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HOW IT WORKS

The Collection

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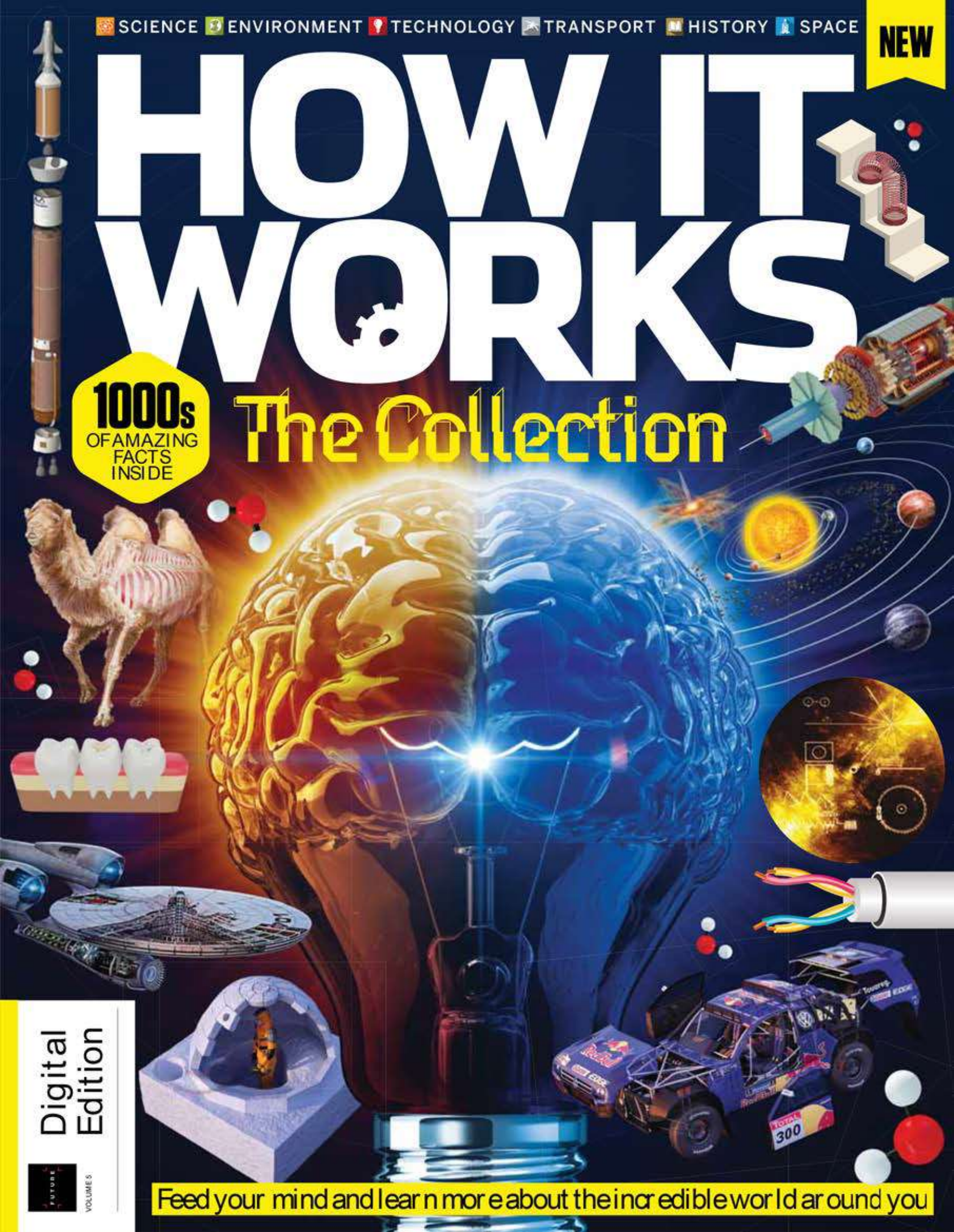

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FUTURE

VOLUME 5

Feed your mind and learn more about the incredible world around you

Welcome to

HOW IT WORKS

The Collection

Volume 5

Welcome to the How It Works Collection, a compendium of fascinating articles peppered with detailed illustrations and cutaways, breathtaking images and of course, packed with mind-blowing facts and stats. Across the categories of science, technology, the environment, transport, space and history, we've gone to the ends of the Earth and beyond to bring you a compelling volume bursting with knowledge.

Perhaps you'd like to know exactly how fish breathe and why we can't breathe underwater? Or what was on the Voyager golden record, why gold is so valuable, or what the world's wackiest and most unbelievable inventions were? We've even got 21 simple life hacks that will change the way you do at least one everyday activity forever. Read on to discover and learn more - enjoy!

FUTURE

HOW IT WORKS
The Collection
Volume 5

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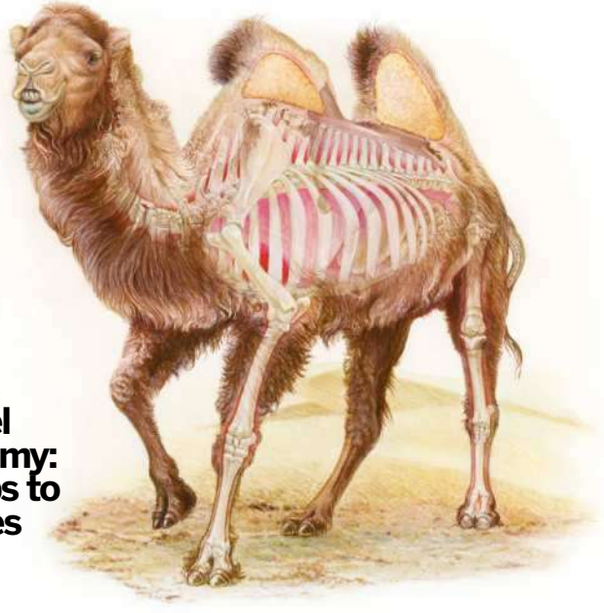

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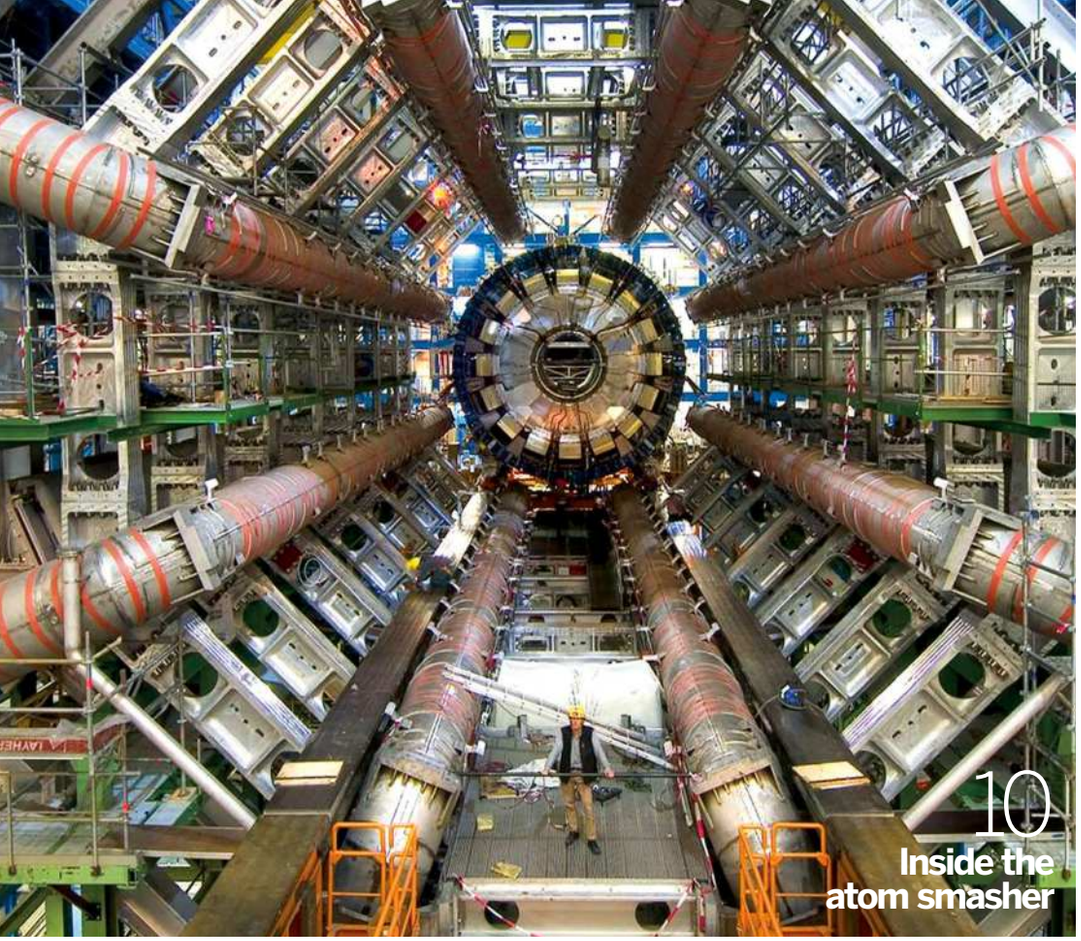

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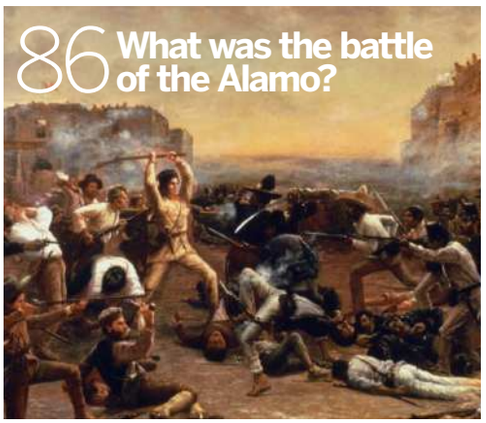

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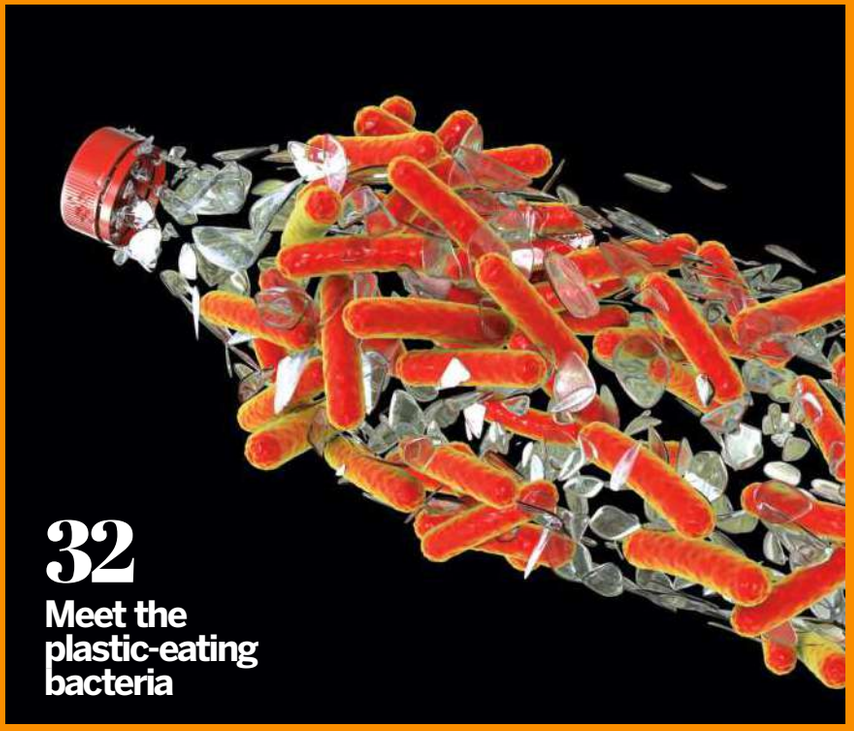

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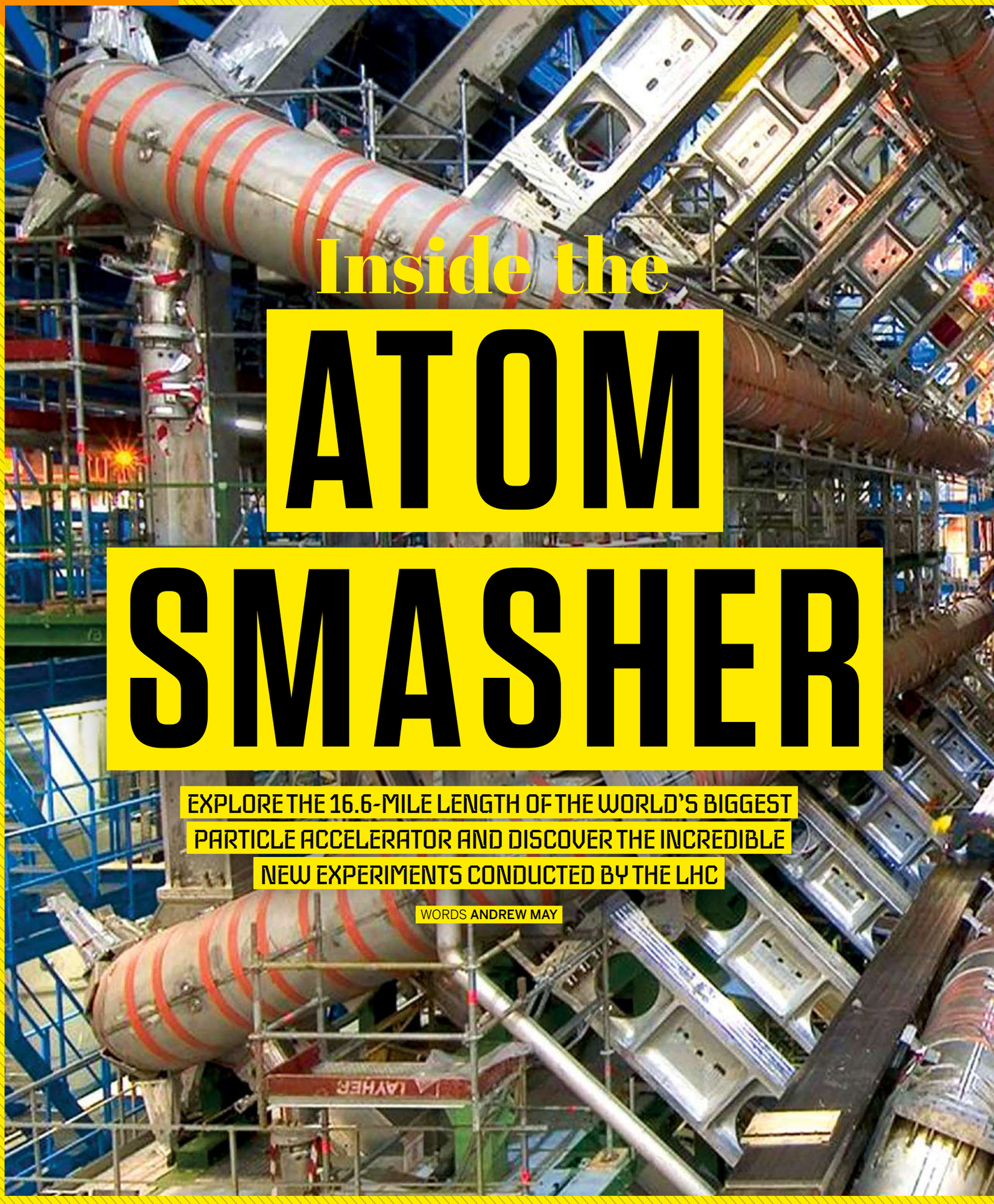
Meet the plastic-eating bacteria

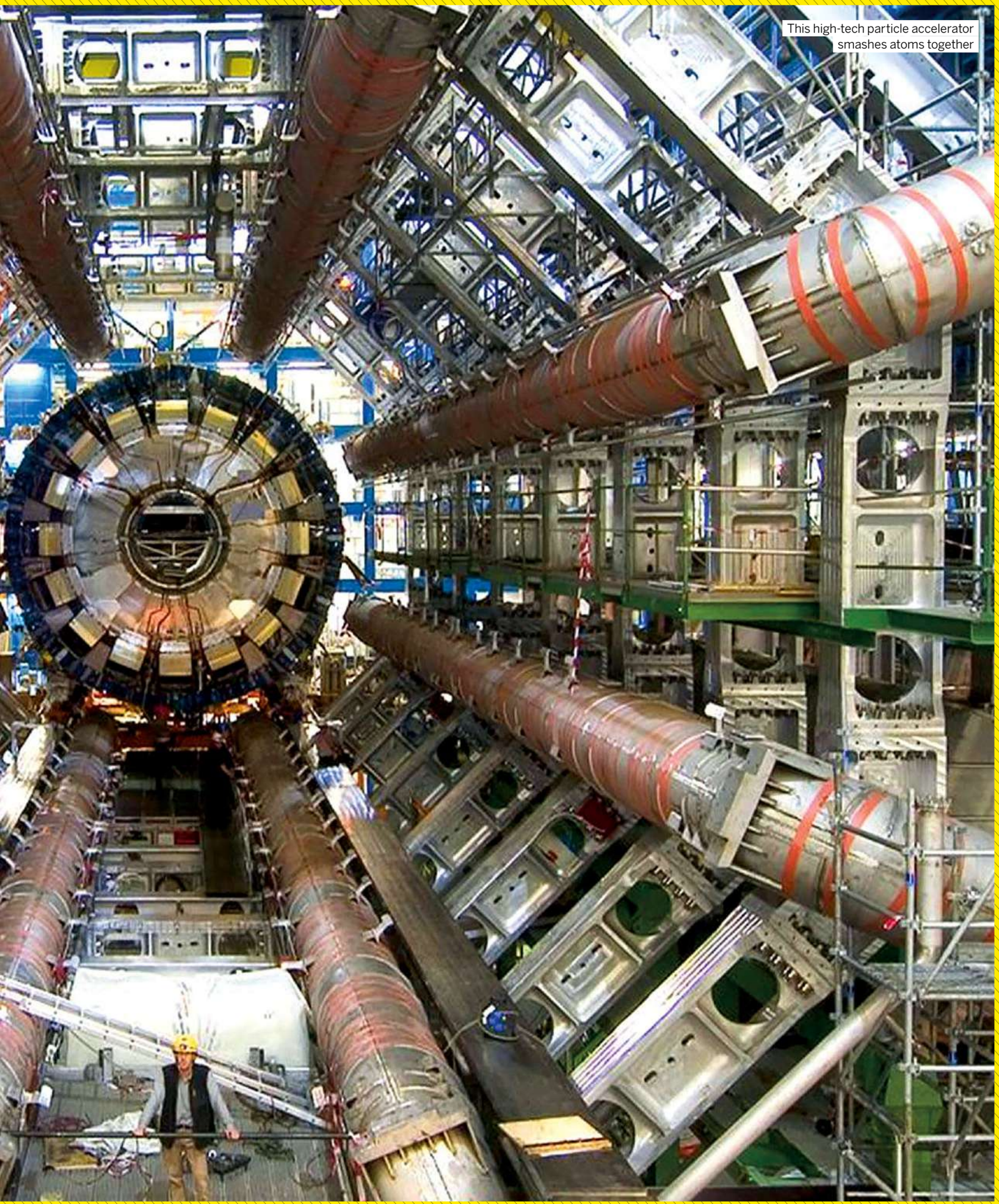


Inside the ATOM SMASHER

EXPLORE THE 16.6-MILE LENGTH OF THE WORLD'S BIGGEST PARTICLE ACCELERATOR AND DISCOVER THE INCREDIBLE NEW EXPERIMENTS CONDUCTED BY THE LHC

WORDS **ANDREW MAY**

DID YOU KNOW? CERN features prominently in Dan Brown's novel Angels and Demons, and the Tom Hanks movie based on it



This high-tech particle accelerator smashes atoms together

If you see a news headline about exotic new subatomic particles, the chances are the discovery was made at CERN, the European Organization for Nuclear Research, located near Geneva in Switzerland. A recent example occurred in January 2022, when CERN scientists announced "evidence of X particles in the quark-gluon plasma produced in the Large Hadron Collider (LHC)". Hiding behind that technospeak is the eye-popping fact that CERN succeeded in recreating a situation that hasn't occurred naturally since a few microseconds after the Big Bang. That particular study drew on pre-existing data from the LHC, the world's biggest particle accelerator, which has been undergoing a major upgrade since 2018. When it restarts this spring after a three-year hiatus, we can expect a whole new spate of discoveries, so it's a good time to take a closer look at what makes the LHC – and the rest of CERN – so unique.

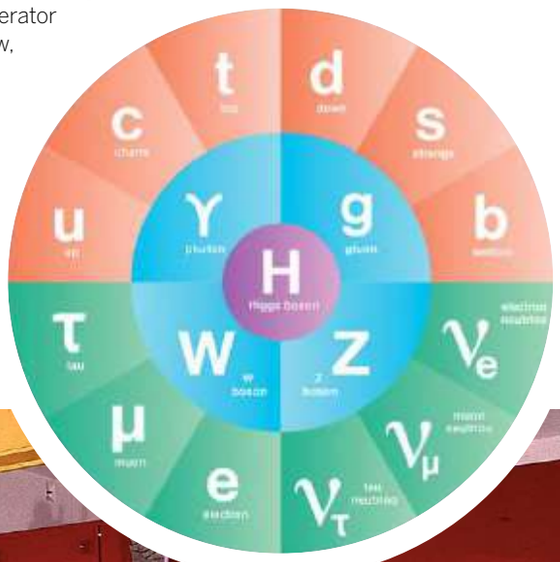
The LHC is a particle accelerator – a device that boosts subatomic particles to enormous energies in a controlled way so that scientists can study the resulting interactions. The 'large' that the L stands for is an understatement; the LHC is by far the biggest accelerator in the world right now, occupying a circular tunnel nearly 17 miles in circumference. The middle letter, H, stands for 'hadron', the generic name for composite particles such as protons that are made up of smaller particles called quarks. Finally, the C stands for 'collider' – the LHC accelerates two particle beams in opposite directions, and all the action takes place when the beams collide.

Like all physics experiments, the LHC's aim is to test theoretical predictions – in this case, the so-called Standard Model of particle physics – and see if there are any holes in them. As strange as it sounds, physicists are itching to find a few holes in the Standard Model because there are some things, such as dark matter and dark energy, that can't be explained until they do.

The LHC's biggest moment came in 2012 with the discovery of the Higgs boson. Although widely referred to as the 'God particle', it's not really as awesome in itself as that name might suggest. Its huge significance came from the fact that it was the last prediction of the Standard Model that hadn't yet been proven.

But the Higgs boson is far from being the LHC's only discovery. It's also found around 60 previously unknown hadrons, which are complex particles made up of various combinations of quarks. Even so, all those new particles still lie within the bounds of the Standard Model, which the LHC has struggled to move beyond, much to the disappointment of the numerous scientists who have spent their careers working on alternative theories. The first tantalising hints that a breakthrough might be just around the corner came last year, when analysis of LHC data revealed patterns of behaviour that indicated small but definite departures from the Standard Model.

The LHC opened for business in 2009, but CERN's history goes back much further than that. The organisation was established in 1954 following a recommendation by the European Council for Nuclear Research – or Conseil Européen pour la Recherche Nucléaire in French, from which it gets its name. Between its creation and the opening of the LHC, CERN was responsible for a series of groundbreaking discoveries, including weak neutral currents, light neutrinos and the W and Z bosons. As soon as the LHC is back up and running, we can expect discoveries to continue.

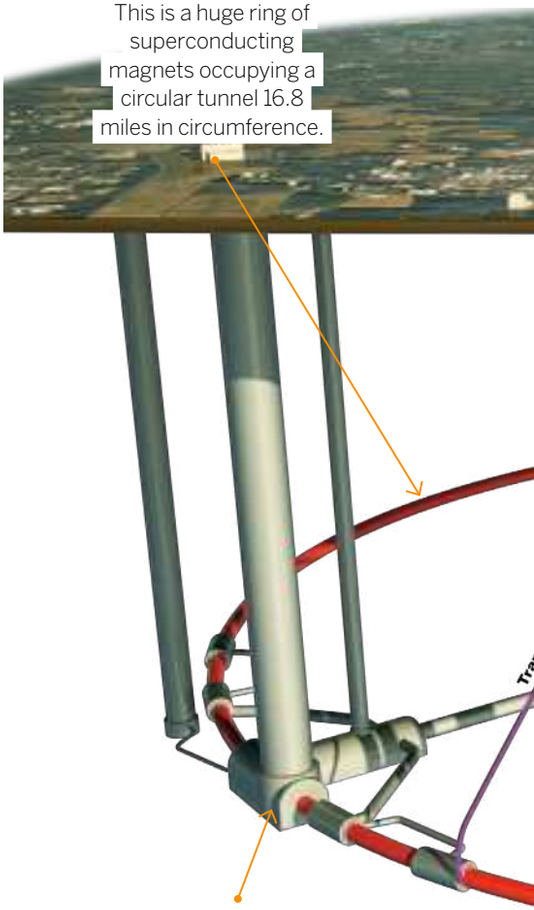


Left: The Standard Model of particle physics consists of 17 elementary particles

Below: CERN's first accelerator, the Synchrocyclotron, began operation in 1957

Did you know?

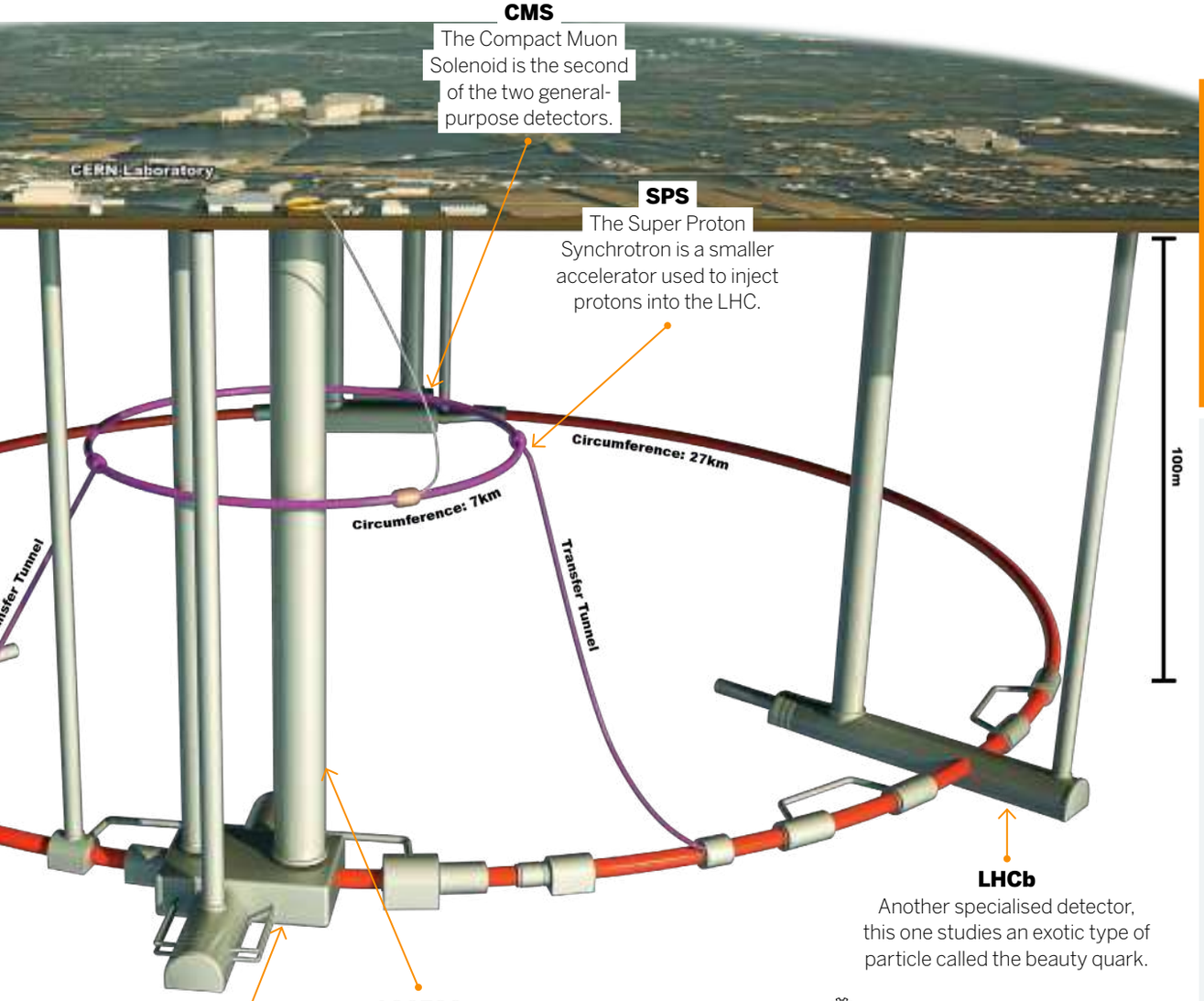
CERN has 23 member states, including the UK



LHC
This is a huge ring of superconducting magnets occupying a circular tunnel 16.8 miles in circumference.

ALICE
This specialised detector looks at collisions between heavy ions, rather than single particles such as protons.

DID YOU KNOW? The LHC will undergo another major upgrade from 2025 to 2027 to create the High-Luminosity LHC (HL-LHC)



CMS
The Compact Muon Solenoid is the second of the two general-purpose detectors.

SPS
The Super Proton Synchrotron is a smaller accelerator used to inject protons into the LHC.

LHCb
Another specialised detector, this one studies an exotic type of particle called the beauty quark.

ATLAS
This is one of the LHC's two principal general-purpose detectors.

ACCESS SHAFTS
Vertical shafts link the underground facilities to buildings on the surface 100 metres above.

GIANT UNDERGROUND LABORATORY

The Large Hadron Collider is located deep beneath the Franco-Swiss border near Geneva

IS CERN DANGEROUS?

People have speculated that experiments at CERN might pose a danger. Take the N in CERN, which stands for nuclear. This has nothing to do with the reactions that take place inside nuclear weapons, which involve swapping protons and neutrons inside nuclei. CERN's research is at a lower level, in the constituents of the protons and neutrons themselves. It's sometimes referred to as 'high-energy' physics, but the energies are only high when viewed on a subatomic scale. Particles inside the LHC typically only have the energy of a mosquito. People have also worried that the LHC might produce a 'mini black hole', but even in the unlikely case this happened, it would be unbelievably tiny and so unstable that it would vanish within a fraction of a second.


There's no danger that CERN would ever explode like a nuclear bomb

5 FACTS ABOUT CERN

1 A WORLD-BEATER
CERN is the largest scientific laboratory in the world, boasting record-breaking facilities. The Large Hadron Collider, for example, is seven times as powerful as any previous particle accelerator.

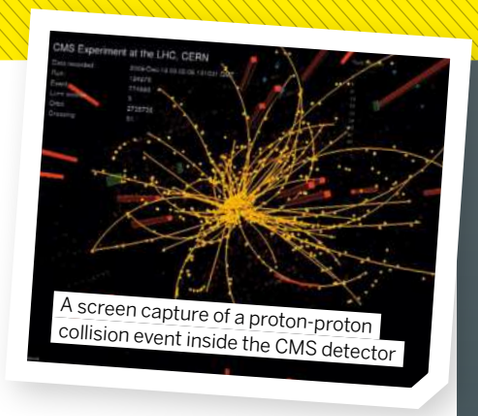
2 A LOT OF DATA
CERN's data centre accumulates over 30 million gigabytes of data every year. That's the same as 250 years of HD video – enough to fill over a million Blu-ray discs.

3 COLDER THAN SPACE
The LHC's superconducting magnets are cryogenically cooled to just 1.9 degrees above absolute zero, or 271.25 Celsius. That's even lower than the 2.7 degrees Kelvin of outer space.

4 ATOMS OF ANTIMATTER
Particle accelerators have always been able to create individual antiparticles, but CERN was first to combine these into atoms of antimatter in the form of antihydrogen.

5 CERN'S GREATEST INVENTION?
Despite its specialised research, CERN has made a major impact on ordinary life through its creation of the World Wide Web, originally as a way for scientists to share information.

HOW THE LHC WORKS



A screen capture of a proton-proton collision event inside the CMS detector

As huge as it is, the LHC can't function without the help of other machines around it. Before particles, which are usually protons but for some experiments are much heavier lead ions, are injected into it, they're passed through a chain of smaller accelerators that progressively boost their speed. Smaller is just a relative term; the last step in the injector chain, the Super Proton Synchrotron, is almost 4.3 miles in circumference. The end result is two beams travelling in opposite directions around the LHC at virtually the speed of light. The beams are kept on their circular trajectories by a strong magnetic field, which has the effect of bending the path of electrically charged particles. At four points around the LHC's vast ring, the opposing beams are brought together and made to collide, and that's where all the science happens.

Did you know?

LHC particles complete 11,000 circuits per second

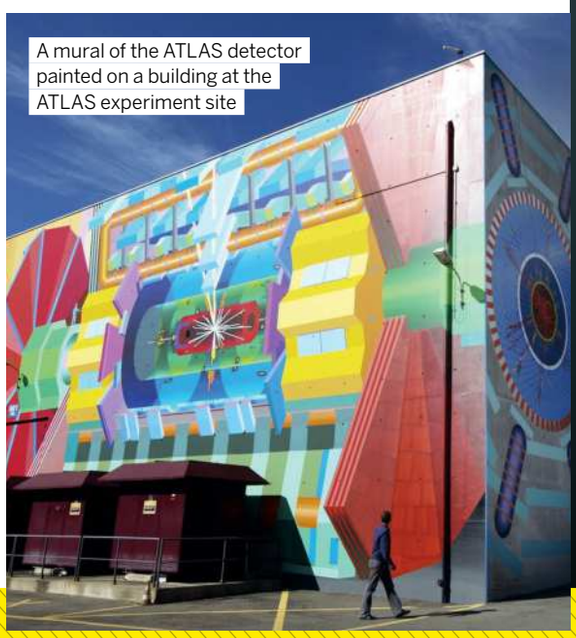
Particles are smashed together with such enormous energies that the collisions create a cascade of new particles – most of them extremely short-lived. The important thing for scientists is to work out what all these particles are, and that's not an easy task. The LHC has an array of sophisticated particle detectors for this purpose, each made up of layers of subdetectors designed to measure certain particle properties or to look for specific types of particles. For example, calorimeters measure a particle's energy, while the curving track of a particle in a magnetic field reveals information about its electric charge and momentum.

Two of the four collision points around the circumference of the LHC are occupied by large general-purpose detectors. These include the Compact Muon Solenoid (CMS), which can be thought of as a giant 3D camera, snapping images of particles up to 40 million times per second. The paths of the particles inside the detector are controlled by a gigantic electromagnet called a solenoid. Despite weighing 12,500 tonnes, it's actually quite compact, as the detector's name suggests. That middle word, muon, refers to an elusive particle similar to the electron but much more massive, which requires its own array of subdetectors wrapped around the solenoid. The LHC's other general-purpose detector, ATLAS (A Toroidal LHC ApparatuS), has an identical purpose to CMS, but differs in the design of its detection subsystems and magnets. It's also less compact than CMS, occupying a greater volume than any other particle detector ever built.

Many of the LHC's most important experiments, including the discovery of the Higgs boson, utilise the general-purpose detectors ATLAS and CMS. But it also has several other more specialised detectors that can be used in specific types of experiments.

The LHC forward (LHCf) detector, located close to the ATLAS interaction point, uses particles thrown forward in collisions as a means of simulating cosmic rays under laboratory conditions. Further along the beam trajectory is the ForwArd Search ExpeRiment (FASER), designed to look for light, weakly interacting particles that are likely to elude the larger detectors. A third experiment optimised for the forward direction is TOTal Elastic and diffractive cross-section Measurement (TOTEM), located near the CMS interaction point, which focuses on the physics of the high-energy protons themselves.

Away from ATLAS and CMS, the LHC has two other interaction points. One is occupied by A Large Ion Collider Experiment (ALICE), a specialised detector for heavy-ion physics. The final interaction point is home to two experiments on the very cutting edge of physics: LHCb, devoted to the physics of the exotic 'beauty quark', and MoEDAL – the Monopole and Exotics Detector at the LHC.


A mural of the ATLAS detector painted on a building at the ATLAS experiment site

THE MAIN DETECTORS

The LHC has two large general-purpose particle detectors, known as ATLAS and CMS

1 COMPACT MUON SOLENOID
Weighing around 14,000 tonnes, the CMS is 28 metres in length and 15 metres in diameter.

2 SUPERCONDUCTING COIL
Essentially a giant electromagnet, this generates a magnetic field 100,000 times as strong as Earth's.

3 COLLISION CHAMBER
The actual particle collisions occur here, in a vacuum chamber at the centre of the detector.

4 CALORIMETERS
Wrapped around the collision chamber, these absorb particles in order to measure their energy.

5 MUON CHAMBERS
Surrounding the collision chamber at a greater distance, these detect muons created by the collisions.

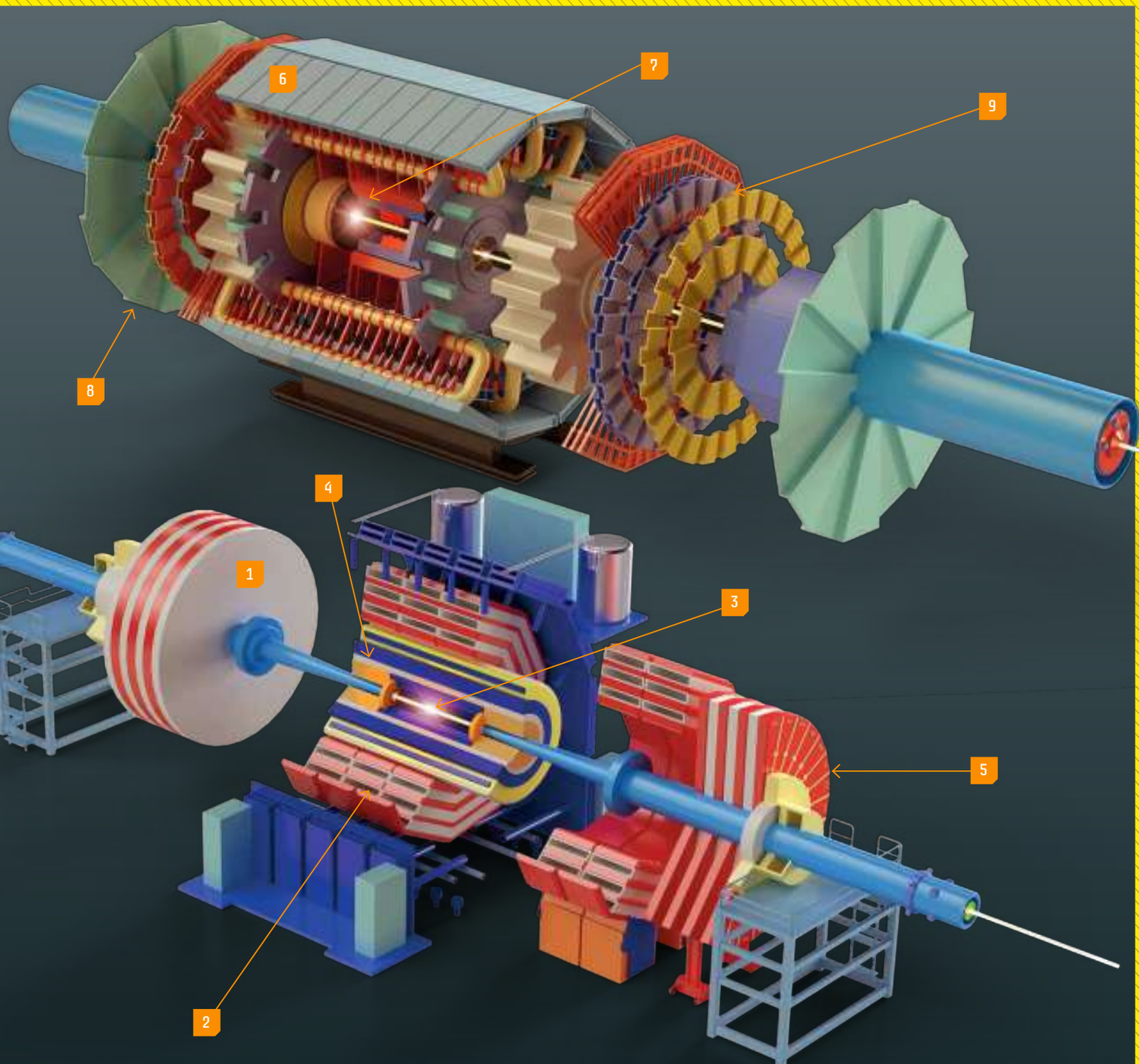
6 ATLAS
At 15 tonnes, this is lighter than the CMS, but it's physically larger: 44 metres long and 22 metres in diameter.

7 INNER DETECTOR
This takes the form of a cylinder 2.4 metres in diameter, wrapped around the central collision chamber.

8 MUON SPECTROMETERS
Like the CMS, ATLAS has several detectors designed to study muons produced in particle collisions.

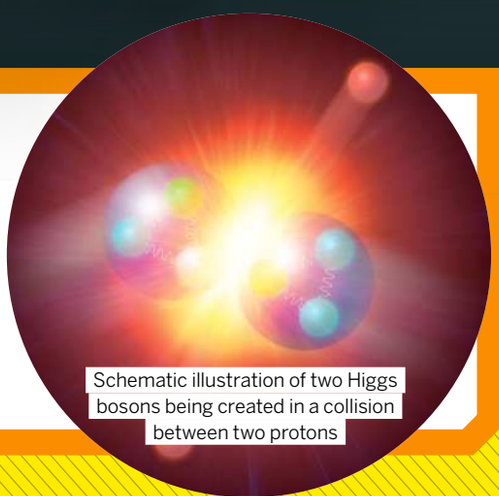
9 TOROIDAL MAGNETS
These create the strong magnetic field needed to produce curved particle tracks.

DID YOU KNOW? Calling the Higgs boson 'the God particle' is a euphemism; it was originally 'the goddamn particle'



THE HIGGS BOSON

When physicists come up with new theories, they always try to make sure they can be tested experimentally. That happened in the early 1960s, when Peter Higgs and others developed a theory to explain why certain force-carrier particles have non-zero mass. The theory predicted the existence of a previously unsuspected particle, dubbed the Higgs boson. The next step was to find the Higgs boson, thus validating the theory. As simple as that sounds, it led to a decades-long hunt around the world. The end finally came in 2012, when data from a combination of ATLAS and CMS measurements proved beyond doubt that the Higgs boson had been discovered.



Schematic illustration of two Higgs bosons being created in a collision between two protons

AR zone

SCAN HERE

CERN'S MANY EXPERIMENTS

One of the key mysteries of the universe is the striking asymmetry between matter and antimatter – why it contains so much more of the former than the latter. According to the Big Bang theory, the universe must have started out with equal amounts of both. Yet very early on, probably within the first second, virtually all the antimatter had disappeared, and only the normal matter we see today was left. This asymmetry has been given the technical name 'CP violation', and studying it is one of the main aims of the Large Hadron Collider's LHCb experiment. All hadrons are made up of quarks, but LHCb is designed to detect particles that include a particularly rare type of quark known as 'beauty'. Studying CP violation in beauty-containing particles is one of the most promising ways to shed light on the emergence of matter-antimatter asymmetry in the early universe.

Did you know?

CERN can make 0.1 picograms of antimatter per day

A view inside the underground cavern housing the LHCb facility

One of the project scientists inside the CLOUD experiment chamber

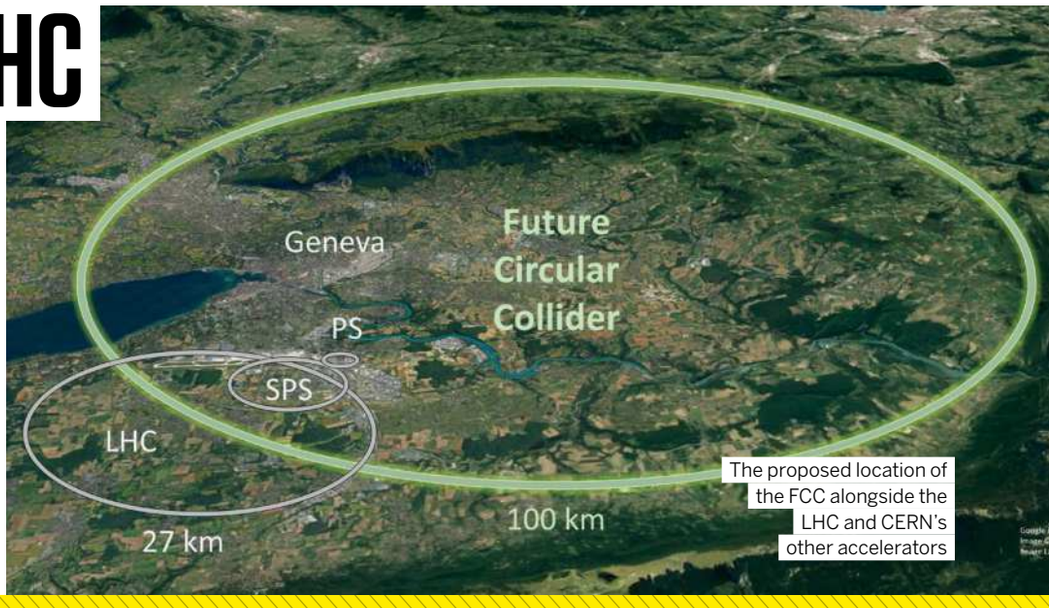
CLIMATE SCIENCE

Away from the LHC, there are other facilities at CERN that are doing equally important research. Linking particle physics to climate science may not be an obvious step, yet that's what one experiment is doing at CERN's Proton Synchrotron.

This is a smaller and less sophisticated accelerator than the LHC, but it's still capable of doing useful work. The climate experiment is called CLOUD, which gives a strong hint of what it's about, although the name actually stands for Cosmics Leaving Outdoor Droplets. Earth is under constant bombardment by cosmic rays, and it's been theorised that these play a role in cloud formation by seeding tiny water droplets. It isn't an easy process to study in the real atmosphere with real cosmic rays, so CERN is creating its own cosmic rays with the accelerator. These are then fired into an artificial atmosphere, where their effects can be studied much more closely.

BEYOND THE LHC

Over 12 years after it entered service, the LHC is still the world's biggest and most powerful particle accelerator. But it won't hold that record forever. Several countries have plans to go a step further, including China's Circular Electron Positron Collider and the International Linear Collider in Japan. Europe's own proposal is the Future Circular Collider (FCC), to be built near the LHC at CERN but dwarfing it in size. Though not yet financially approved – the estimated cost is £20 billion ($27 billion) – the design is well advanced. The FCC would be 62 miles in circumference and sit alongside the LHC, which it would use as a particle injector, ultimately achieving energies seven times greater than its predecessor.

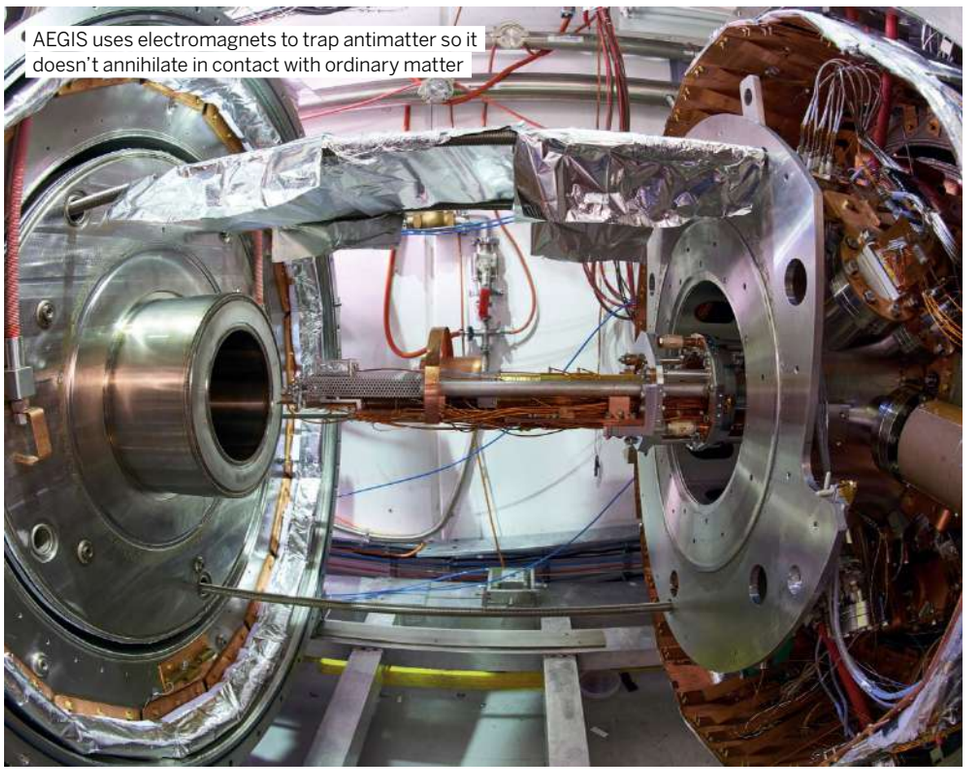


The proposed location of the FCC alongside the LHC and CERN's other accelerators

MAKING ANTIMATTER

Antimatter often pops into existence inside CERN's high-energy accelerators as one half of a particle-antiparticle pair. But in the usual course of events, the antiparticles don't last long before they're annihilated in collisions with ordinary particles. If you want to create antimatter that stays around long enough for detailed study, you need more than just an accelerator. This is where CERN's unique 'antimatter factory' comes in.

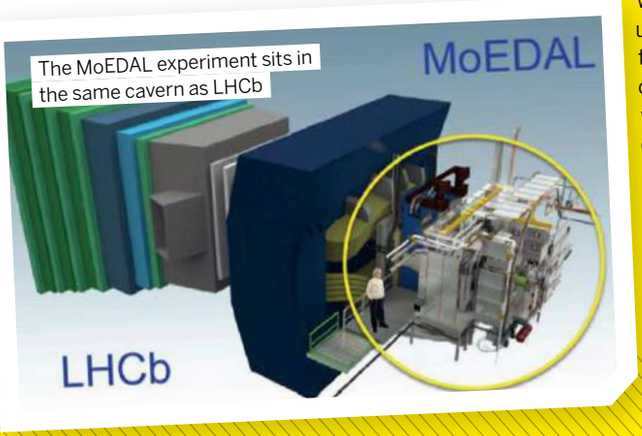
It takes antiparticles created in the Proton Synchrotron and slows them down to manageable speeds in what is effectively the exact opposite of a particle accelerator: the Antiproton Decelerator. The resulting 'antiatoms' can then be studied by a range of instruments, such as AEGIS (Antihydrogen Experiment: Gravity, Interferometry and Spectroscopy). One question that AEGIS should be able to answer soon is the fascinating one of whether antimatter falls downwards in a gravitational field, like ordinary matter, or upwards in the opposite direction.



AEGIS uses electromagnets to trap antimatter so it doesn't annihilate in contact with ordinary matter

HUNTING EXOTIC PARTICLES

Sharing the same cavern as LHCb is a smaller instrument called MoEDAL, which stands for Monopole and Exotics Detector at the LHC. While most CERN experiments are designed to study known particles, this one is aimed at discovering unknown ones that lie outside the Standard Model. A monopole, for example, would be a magnetised particle consisting only of a north pole without a south one, or vice versa. Such particles have long been hypothesised, but never observed. The purpose of MoEDAL is to look out for any monopoles that might be created in collisions inside the LHC. It could also potentially detect certain 'stable massive particles' that are predicted by theories beyond the Standard Model. If it's successful in finding any of these particles, MoEDAL could help resolve fundamental questions such as the existence of other dimensions or the nature of dark matter.



The MoEDAL experiment sits in the same cavern as LHCb

Dr Clara Nellist standing next to the ATLAS detector at CERN

WORKING WITH THE LHC

We speak to CERN scientist Clara Nellist about her work with the LHC's ATLAS detector

How did you come to be involved with the ATLAS experiment?

I started on ATLAS for my PhD research. I was developing new pixel sensors to improve the measurement of particles as they pass through our detector. It's really important to make them resistant to radiation damage, which is a big concern when you put the sensors close to the particle collisions. Since then, I've had the opportunity to work on a number of different projects, such as understanding how the Higgs boson and the top quark interact with each other. Now I'm applying machine learning algorithms to our data to look for hints of dark matter. One of the biggest mysteries in physics right now is, what is 85 per cent of the matter in our universe? We call it dark matter, but we don't actually know much about it!

What's it like working with such a unique and powerful machine?

It's really amazing to be able to work on this incredibly complicated machine with people from all over the world. No one person can run it all, so each team becomes an expert on their specific part. When we all work together, we can make discoveries about the smallest building blocks of our universe.

Are there any exciting new developments you're particularly looking forward to?

We're starting the Large Hadron Collider up again this year, so I'm really excited to see what we might find with it. Part of our work is to understand the particles we already know about in as much detail as possible to check that our theories match what we measure. But we're also looking for brand-new particles that we've never seen before. If we find something new, it could be a candidate for dark matter, or it could be something completely unexpected.

MEET YOUR TEETH

How these pearlescent facial features develop and are maintained in a healthy mouth

WORDS **JAMES HORTON**

Your teeth offer so much more than just a winning smile. Alongside your tongue and saliva, teeth are integral for mastication, which is the process of breaking down food that enters the mouth into a bolus – a chewed ball of food – fit for swallowing. Teeth are also surprisingly complex components. They are formed of many layers, are organised into various functional shapes and erupt from the gumline at structured times during our development.

Teeth are supported in the mouth by the jawbone and gums, which surround and protect the lower features of each tooth. Teeth are not attached directly to the jawbone, but are linked to it via a strip of tissue known as the periodontal ligament. This ligament acts as a shock absorber for the jawbone, helping to ensure comfort when a tooth is exerting pressure on food and other teeth.

The periodontal ligament is connected to a thin layer of cementum, which provides a protective outer layer for the tooth's root. Encased within this layer, the horseshoe-shaped root sits embedded in the bone, helping to keep the tooth locked in place. As well as this, the root plays host to the pulp canals – a network of blood vessels and nerves that carries nutrients and signals to the rest of the tooth. The pulp canals coalesce into a pulp chamber above the root, but in healthy teeth the pulp chamber remains unseen, as it is covered by a protective sheath.

The immediate barrier surrounding the sensitive pulp is called dentin, which forms the largest bulk of the tooth. Formed of many tiny tubes, dentin is hard, but remains vulnerable to agents of decay. The outermost layer of the tooth, which forms the visible surface known as the crown that we see when looking at a healthy set of teeth, is formed of enamel. Enamel is almost entirely composed of unliving crystals containing calcium and phosphate, and in adult teeth it is the hardest substance of the body.

DID YOU KNOW? It's been estimated that up to 37 per cent of adults fail to develop at least one of their wisdom teeth

ERUPTION

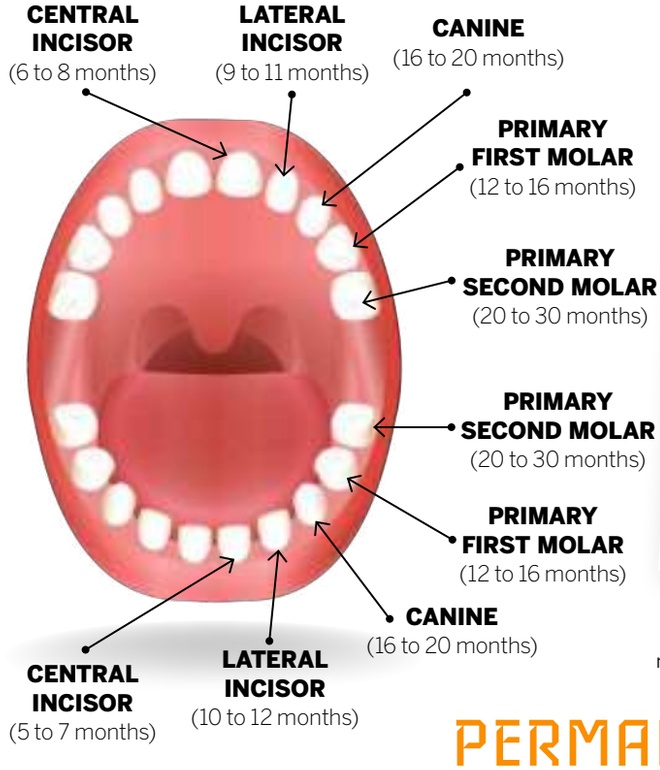
Humans, like our ape cousins and many other mammal species, are diphyodonts. This means we have two sets of teeth: an initial 'baby', or deciduous set, and an 'adult' permanent set that follow. In humans, the phases of growth in our teeth offer many advantages. The delayed eruption of our first teeth allows mothers to nurse more comfortably. And replacing the smaller deciduous teeth with larger, permanent teeth as a child ages accommodates the rapid increase in head and jaw size that occurs as we mature.

Most permanent teeth are in place by the age of 13, as these teeth erupt from underneath the deciduous set and dislodge them. However, wisdom teeth – also known as the third set of molars – do not appear until early adulthood, if at all. Wisdom teeth play a modest role in assisting with mastication, and so offer little advantage to the modern human. Due to the lateness of their arrival and the limited space available in the gumline, wisdom teeth can also unsettle the other molars and cause pain and discomfort. As such, many adults have their wisdom teeth removed, and others never get them, leading to the idea that humans may be evolving away from a third set of molars.

Permanent teeth form beneath the gumline during development and push deciduous teeth out on their way to eruption

DECIDUOUS

Your first set of teeth erupt from the gums at around six months old

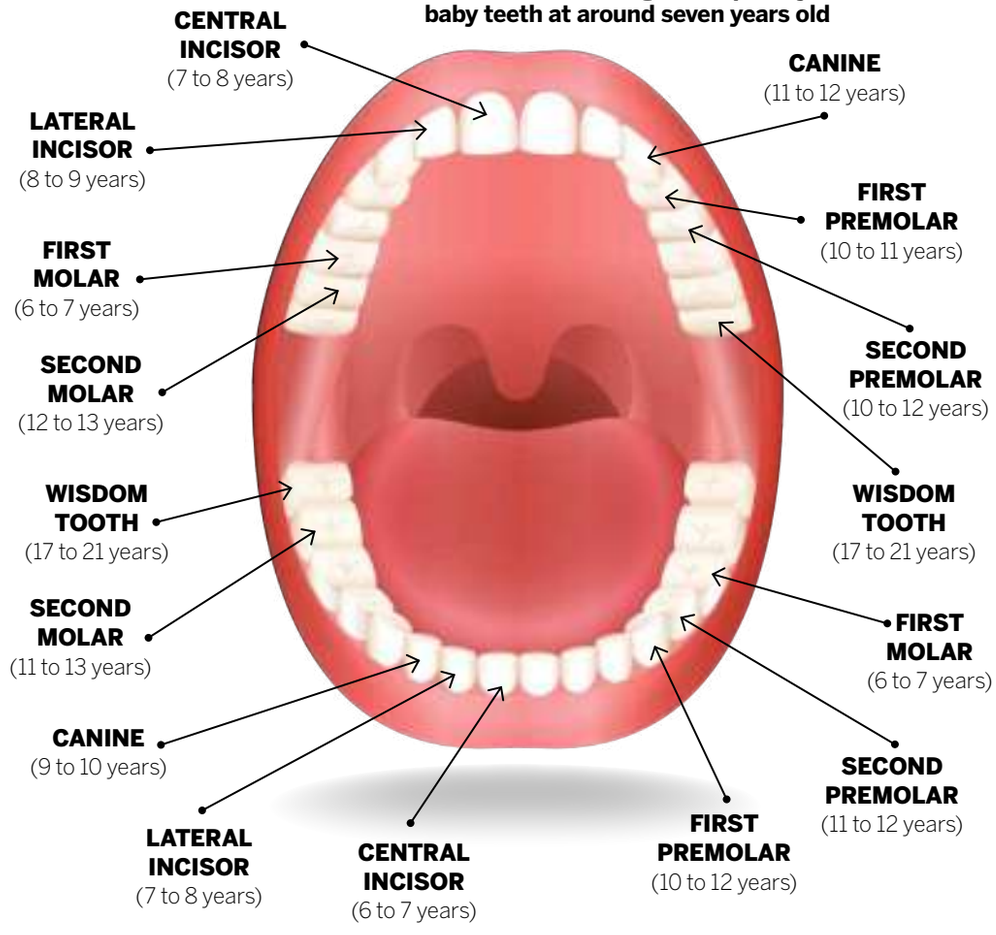


"Teeth are supported in the mouth by the jawbone and gums"

The eruption of wisdom teeth can be partially or totally blocked by other molars, a process known as impaction

PERMANENT

Your second teeth begin to replace your baby teeth at around seven years old



BUILDING PLAQUE AND TARTAR


Streptococcus species can be identified in the oral cavity by spreading saliva onto diagnostic agar in the laboratory

Your teeth and gums are under constant threat from other residents of the oral cavity

As the hardest substance in the human body, with a composition of mostly hardy minerals, a tooth's outer enamel surface is well equipped to handle wear and tear. This is especially important, as permanent teeth in humans are, as their name entails, intended to be a permanent feature. There are no natural replacements available to us if we lose a tooth. However, food itself is not the only threat to the integrity of our teeth, because our mouths are by no means unoccupied. They are home to hundreds of different bacterial species, together numbering in their billions. These tiny microorganisms may be invisible to the naked eye, but they can wreak more havoc on our oral health than the largest and toughest piece of food.

Just as great, sturdy mountains are eventually toppled by a multitude of tiny erosions, so too can the hard surface of enamel be eventually worn away by the swarm of bacteria residing in the oral cavity. Bacteria's primary ability to achieve this erosion is through the formation of plaque. Bacteria feed on the food we eat just as we do, and readily metabolise sources of energy such as sugar and carbohydrates to create harmful acids. This cocktail of compounds and microorganisms can then fuse to form a type of biofilm – colloquially referred to as 'bacterial cities' – known as plaque. If left unchecked, plaque can readily harden into a calculus, also known as tartar, which is much more difficult to remove and yet more damaging to teeth and the gumline.

> "This cocktail of compounds and microorganisms fuses to form a 'bacterial city' known as plaque"

But the human body is not without natural defences designed to mitigate bacterial damage to the oral cavity. After all, for much of human history we have been without the means to properly clean and look after our teeth with dental brushes, toothpaste and flossing tape.

Fortunately, our saliva contains a battery of compounds that help keep bacteria in check. The

DARK HISTORY OF DENTISTRY

Although ancient civilisations didn't feast on as many plaque-inducing foodstuffs as we do in modern times, people still suffered tooth problems. This meant that the occupation of dentistry came into existence thousands of years ago, although at its outset was mostly useless.

Roman scholar Pliny suggested a cure for toothache could be found by imploring a frog to cure you by moonlight. Scribonius Largus offered a more reasonable suggestion, including washing the mouth with hot water, but the effectiveness of this was likewise limited. If a tooth needed to be removed, ancient dentists wrestled them free with forceps made from bone or boxwood.


Barber surgeons were a one-size-fits-all medical practitioner and groomer – they regularly pulled teeth in the UK until the mid-18th century

THE CHEMISTRY OF PLAQUE

How bacteria residing in the oral cavity utilise your dinner to form a plaque paradise

1 DINNER TIME
Colonising bacteria utilise energy from ingested sugar, available in the oral cavity, to lay the foundation of plaque.

2 SETTING THE STAGE
The colonisers produce molecules known as glucosyltransferases (GTFs), which facilitate the production of cavity-causing, or cariogenic, plaque.

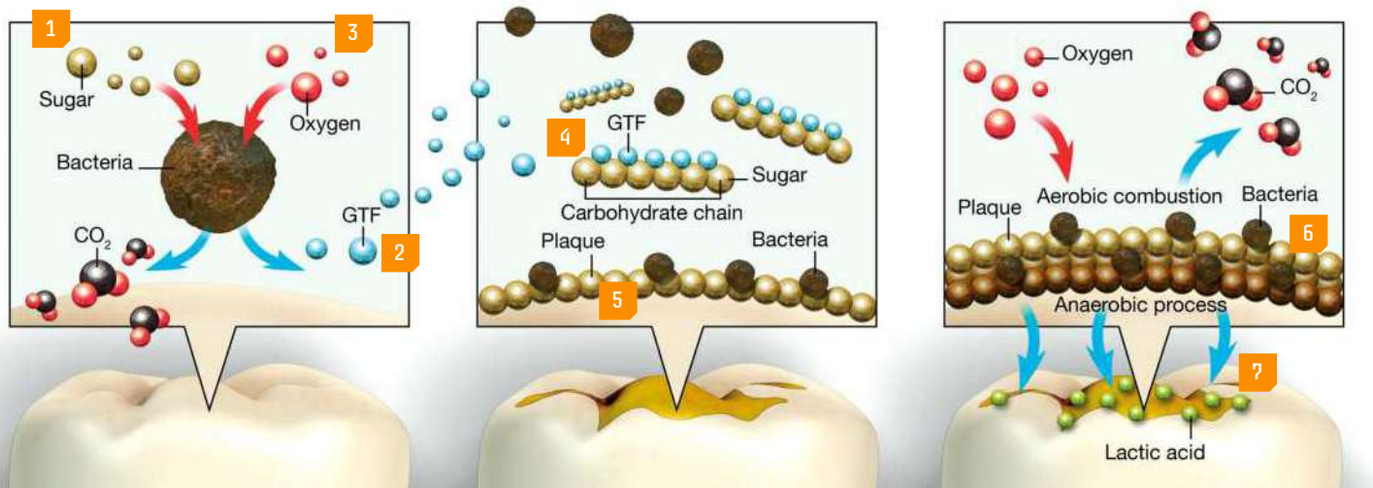
3 EXPOSED
Prior to producing a biofilm, bacteria are readily exposed to oxygen and so can undergo aerobic – or oxygen-utilising – processes.

4 COMING TOGETHER
GTFs perform numerous functions, binding both to sugars and other bacteria for incorporation into plaque.

5 ASSEMBLY
Colonising bacteria and some GTFs stick to the enamel surface, while other GTFs break sugar into glucans, which then also join the budding matrix.

6 UNDER COVER
As the plaque expands, the encased bacteria are separated due to oxygen exposure, creating an anaerobic environment.

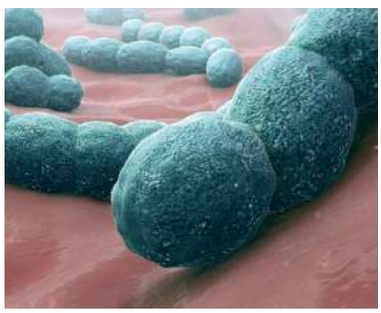
7 ACID TEST
Deep within the biofilm, against the enamel, bacteria undergo anaerobic respiration, creating lactic acid as a by-product, which erodes the tooth.



amylase enzymes dissolve carbohydrates in the mouth, denying bacteria a bounty from a piece of food lodged between two teeth. Additionally, mucins glycoproteins adhere to bacteria and remove them from surfaces where they can be harmful. However, in many modern societies, saliva alone is not enough to combat bacterial proliferation. Modern diets are laced with carbohydrates and sugars that were considerably more scarce for our hunter-gatherer ancestors, and the rate of tooth decay has increased as a result. We also produce less saliva when we sleep, because we spend a lot of time not chewing during the night, and this grants near free reign to our mouths' bacterial inhabitants. A testimony to the increase in bacteria while we sleep is halitosis, or 'morning breath', of which unchecked bacterial division is the primary cause. For many leading today's lifestyle, it's important that we regularly brush and floss to remove food debris and plaque before the latter hardens into calculus – especially before bed.

EARLY BACTERIAL COLONISTS

Both tooth decay and gum disease are predominantly owed to the activity of bacteria. The oral microbiome, which describes the bacterial community that has taken residence in the oral cavity, is a diverse one, with over 600 species being present in some individuals. These bacteria first arrive in the mouth shortly after birth, where often a group of bacteria known as streptococcus spearhead the colonisation charge. Streptococci are adept at producing adhesive molecules, and so are well suited for establishing themselves across the different niches found in the mouth. They're also efficient metabolisers of carbohydrates, which they achieve via a process of fermentation that creates harmful acids as a by-product.



Species from the genus Streptococci act as forerunners for establishing microbiomes in the oral cavity

STAGES OF TOOTH DECAY

How bacterial erosion gnaws away at the integrity of the tooth

1 A PROTECTIVE COATING
In a healthy tooth, the vulnerable network of blood vessels and nerve endings, and the softer dentin bulk, are protected by enamel on the crown and cementum at the roots.

2 ESTABLISHMENT OF PLAQUE
Bacteria, food debris and a sweep of small molecules aggregate into a biofilm known as plaque. Over time plaque hardens into calculus, which is difficult to remove.

3 EROSION
Harmful acids produced by colonising bacteria slowly wear away at the hard mineral structure of the enamel, making contact with the softer and more sensitive dentin underneath.

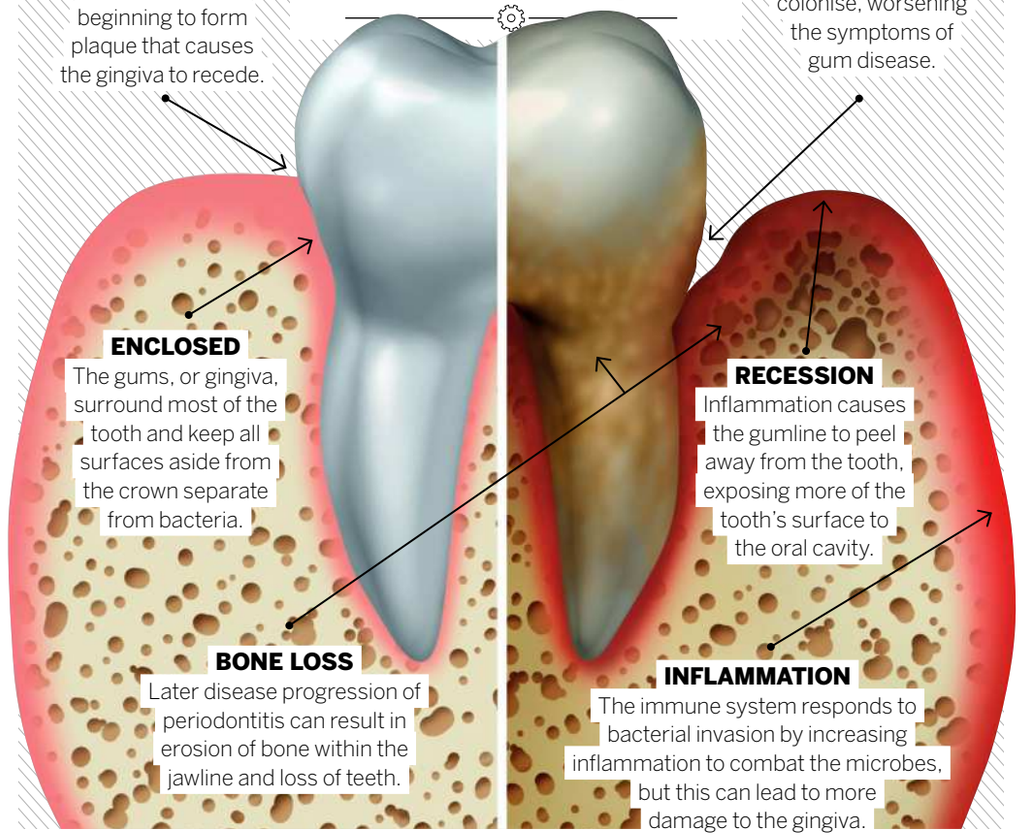
4 INFECTION
Once bacteria chips through the dentin it arrives at the pulp, a sensitive bundle of nerves and blood vessels. This often results in a serious infection which can destroy the tooth.

PERIODONTAL DISEASE PROGRESSION

The progression from mild gingivitis to periodontitis can cause irreversible damage to the gumline

BASE CAMP
Bacteria can colonise the area where the gumline meets the tooth, beginning to form plaque that causes the gingiva to recede.

POCKETS
Crevices that appear following recession provide new niches for bacteria to colonise, worsening the symptoms of gum disease.



ENCLOSED
The gums, or gingiva, surround most of the tooth and keep all surfaces aside from the crown separate from bacteria.

RECESSION
Inflammation causes the gumline to peel away from the tooth, exposing more of the tooth's surface to the oral cavity.

BONE LOSS
Later disease progression of periodontitis can result in erosion of bone within the jawline and loss of teeth.

INFLAMMATION
The immune system responds to bacterial invasion by increasing inflammation to combat the microbes, but this can lead to more damage to the gingiva.

DENTAL REPAIRS

A trip to the dentist can fix many oral issues

Did you know?
Sharks typically lose at least one tooth per week

Despite our best efforts, sometimes teeth and gums require professional treatment. With gums this usually involves cleaning via a process known as a scale and polish, where a dental hygienist will use specialised tools to remove calculus that has accumulated on the teeth and around the gumline. For people with periodontal issues, calculus can build up even when following a rigorous oral hygiene regimen. Therefore routine visits to the hygienist are essential for keeping gum disease at bay.

There are a plethora of treatment options available for teeth. When erosion occurs, the tooth becomes susceptible to infection, requiring the use of fillings to seal the breach point and protect the tooth from further damage. If the infection has made its way into the pulp and the blood supply has become infected, however, a more invasive treatment is required. Known as a root canal, this process involves physically removing bacteria from the root by removing the pulp from the tooth, then filling in the cavity with composite materials.

Above: Hygienists use specialist tools to remove hardened calculus, which cannot be removed easily at home

Top: Some types of dental implant involve drilling the replacement tooth directly into the jawbone

For people who've had their teeth broken, knocked out or removed because of infection or disease, there are also now many forms of replacement teeth. Some of these, such as veneers and crowns, attach to a part of the natural tooth, though in both cases the tooth is sometimes carved down to a point before attachment. When the natural tooth is completely missing, treatments such as bridges or dental implants, which involve drilling the replacement tooth into the jawbone, can be used to affix permanent replacements.

FILLING MATERIALS

AMALGAM

1 Made of a metal mixture containing mercury, silver and others, these have been used by dentists for well over 100 years. They are durable fillings that can protect a tooth over multiple decades.

COMPOSITE

2 Although not as hardy as amalgam or gold, composite fillings are made from a combination of ceramic particles and are tooth-coloured, allowing a filling to appear more organic.

GOLD

3 Unlike composites and amalgam, gold fillings are made in laboratories following dental impressions. Although more expensive and labour-intensive, gold fillings are strong and do not tarnish, allowing them to last for many years.

DID YOU KNOW? The first toothpaste was mass produced in 1873 by Colgate, with toothbrushes produced around the same time

THE INGREDIENTS OF TOOTHPASTE

Scrub up on your knowledge of the common components found in a tube of toothpaste

TRICLOSAN
Only used in marketed antimicrobial toothpastes, triclosan is an antibacterial agent that has been shown to reduce gum inflammation, or gingivitis.

SORBITOL
As a natural sweetener and humectant, sorbitol adds both sugar-free flavour to the toothpaste and helps prevent it from drying out and becoming crumbly.

SODIUM FLUORIDE
Fluoride is the key component of most toothpastes. This mineral helps prevent cavities by strengthening the enamel on your teeth.

LAURYL SULPHATE
Detergents help toothpaste become foamy as you brush. This is important for ensuring dispersal of the toothpaste so it can efficiently coat the teeth.

CALCIUM CARBONATE
Abrasive components such as calcium carbonate are used to remove surface stains and small pieces of debris from the teeth.

5 FACTS ABOUT TEETH

1 INCISORS ARE TROUBLEMAKERS
Lateral incisors can suffer from a spectrum of defects, such as missing enamel, a duplication of the tooth or an absence of the tooth. This is a consequence of how they develop in the jaw.

2 VERSATILE JAW MUSCLES
The muscles of the jaw generate the most power when compressing teeth vertically. However, humans can also shift their jaw forwards and side to side to assist compression chewing with sheer force.

3 TWO SETS ISN'T ENOUGH
Unlike mammals, other animals such as reptiles and toothed fishes boast polyphyodont dentition, which means they constantly replace their teeth until their tooth buds are completely depleted.

4 ADDITIONS, NOT SUBSTITUTIONS
Although deciduous back teeth are known as 'molars', their permanent successors are premolars. Permanent molars are additional teeth that only appear once the jaw is large enough to accommodate them.

5 TEETH ARE FOR TALKING
As well as helping us mechanically break down our food, teeth are also important for speech. Teeth are especially important for making 'F', 'V' and 'Th' sounds.

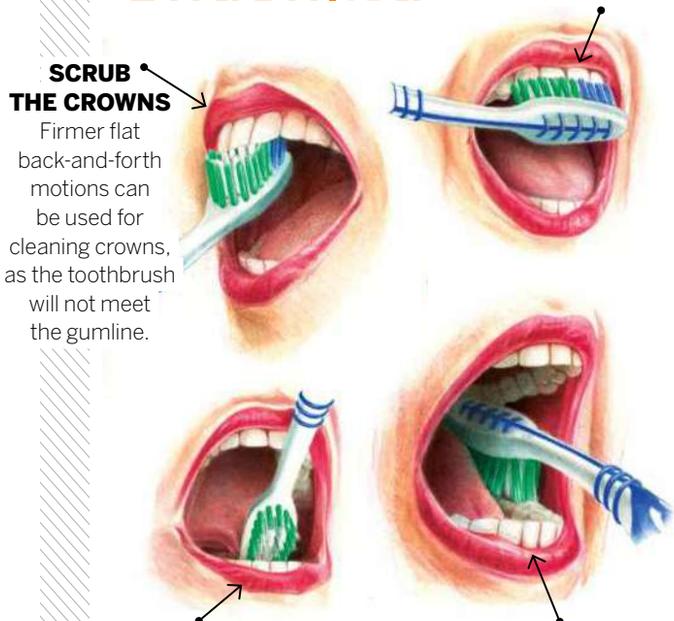
KEEPING CLEAN

A handy guide to help you stay on top of your dental hygiene

BRUSHING

CHECK YOUR ANGLE
Hold your toothbrush at a 45-degree angle as you perform gentle and short back-and-forth motions.

SCRUB THE CROWNS
Firmer flat back-and-forth motions can be used for cleaning crowns, as the toothbrush will not meet the gumline.



BE GENTLE TO GUMS
Maintain the 45-degree angle when trying to clean your gumline, as this will help prevent excessive abrasive contact that can cause recession.

DON'T FORGET THE BACK
Use gentle up-and-down strokes to clean the backs of your incisors.

FLOSSING

ANTI-PLAQUE
Floss can be gently raised slightly above the gumline, permitted no resistance is met, to ensure plaque is removed.

TIGHT GAPS
Gently work the floss between teeth with small gaps using a see-sawing motion, then use an up-and-down motion to remove plaque and debris.

THE CHEMISTRY OF TEA & COFFEE

Whichever of these hot beverages you prefer, find out exactly what you're drinking

WORDS BY **BALJEET PANESAR**

For many of us, our day starts with a cup of coffee or tea. Without them, many of us simply wouldn't be able to think straight in the morning, and some of us continue to rely on tea and coffee to feel mentally alert during the day. We even drink tea and coffee as a social activity, whether that's with our friends, colleagues or on a date. Together they are two of the most popular beverages in the world, with more than 2 billion cups of coffee and 3.7 billion cups of tea consumed globally each day.

Both tea and coffee contain hundreds of compounds that give them their aroma and flavour, but one well-known component of both is caffeine, a stimulant that acts on the central nervous system and the compound that gives us that characteristic 'buzz'. Each type of tea – there are six different types: black, green, white, oolong, yellow and pu-erh – comes from the Camellia sinensis plant, but all have different tastes. This is due to how the leaves are processed after they've been picked. Black and oolong tea undergo a process called oxidation, where the enzymes in the leaves react with the oxygen in the air.

Another interesting group of compounds found in our hot beverages are polyphenols. They have antioxidant properties that protect against heart disease and cancer, as well as contributing to the taste and colour of tea and coffee. Different polyphenols are found in both: black tea contains theaflavins, thearubigins and catechins, while coffee contains chlorogenic acid and flavonoids. Whether you drink coffee to wake up or tea to relax, these are the chemicals that make your favourite hot drink.

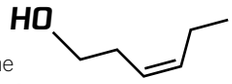
DID YOU KNOW? Ottoman Sultan Murad IV made drinking coffee a capital offense

THE AROMAS OF TEA

Different compounds make up the characteristic smell of tea

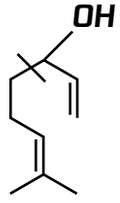
(Z)-3-HEXEN-1-OL

This is the main compound that contributes to the distinctive smell of tea.



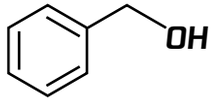
LINALOOL

A floral, sweet-smelling molecule that is mostly found in oolong and black tea.



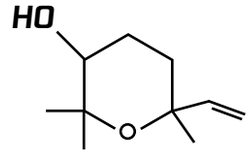
BENZYL ALCOHOL

This naturally occurring compound gives tea its sweet, honey-like smell.



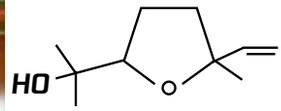
PYRANOID

An oxide of linalool, it gives tea an earthy aroma. It can be found in green, black and oolong tea.



FURANOID

Another oxide of linalool, it too has a sweet and floral aroma, but also a creamier scent, too.



THE HISTORY OF TEA AND COFFEE

Tea and coffee have been around for millennia, so their origins are surrounded by mystery and folklore. According to legend, tea was made 5,000 years ago in ancient China by Emperor Shennong after tea leaves flew into a boiling pot of water. As a renowned herbalist, Shennong decided to taste the infused water concoction, and so tea was born. After its serendipitous discovery, tea became increasingly popular, and was used as an aid for digestion and in tea ceremonies as well.

Some 3,000 years later, an Ethiopian goat herder called Kaldi noticed his goats behaving erratically after eating red berries from the Coffea arabica tree. Having tried some himself, Kaldi also experienced similar effects to the goats, earning him the moniker of 'the happiest herder in happy Arabia'. But this is just a story. The Oromo people are thought to have chewed the coffee plants' beans and leaves for thousands of years before, and they would mix them with fat to make 'power' bars.

Tea plants grow in warm climates and can reach heights of 18 metres

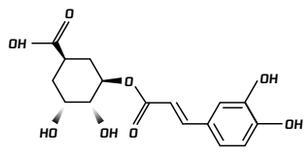
INSIDE A CUP OF COFFEE

Coffee contains over 1,000 compounds. Here's just a small selection that can be found in your coffee cup

Arabica coffee makes up 60 per cent of all coffee worldwide. Robusta makes up the other 40 per cent

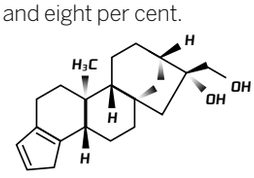
CHLOROGENIC ACID

Much of the bitter taste of coffee comes from chlorogenic acid. This antioxidant and anti-inflammatory may also help reduce the risk of developing type 2 diabetes and heart disease.



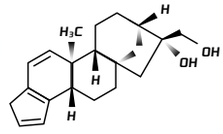
CAFESTOL

Cafestol reduces the body's ability to regulate cholesterol levels. Drinking five cups of unfiltered coffee for four weeks can increase cholesterol between six and eight per cent.



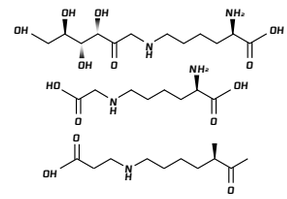
KAHWEOL

Like cafestol, kahweol can also cause an increase in blood cholesterol levels. But it also has anti-inflammatory and anticancer properties.



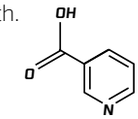
MELANOIDINS

Melanoidins are formed during the roasting process. These compounds are responsible for the change in colour of the coffee beans from green to brown.



TRIGONELLINE

This molecule gives coffee its sweet, earthy taste. It also fights cavity-causing bacteria Streptococcus mutans and stops them from attaching to your teeth.



CAFFEINE CHEMISTRY

How caffeine wakes you up

Caffeine is the common name for trimethylxanthine, and is naturally produced by several plants, including coffee beans, cacao beans and tea. It was first isolated from coffee beans by German chemist Friedlieb Ferdinand Runge in 1819. In its pure state it is a white powder, which can also be added to soft drinks. A German merchant called Ludwig Roselius completed the first commercially successful decaffeination of coffee in 1903.

Runge was also one of the first scientists to isolate quinine, a drug that's used to treat malaria

© Alamy

DOPAMINE
Dopamine is responsible for pleasure, pain, emotions and muscle control.

ADENOSINE
Adenosine, a neurotransmitter, is produced in the brain and binds to adenosine receptors, making us feel sleepy and more relaxed.

DOPAMINE ACTIVITY
Caffeine-binding makes dopamine receptors more active, which makes us feel good. A similar effect can be observed when we eat chocolate.

FOOLING ADENOSINE
Caffeine has a similar structure to adenosine, allowing caffeine to bind to adenosine receptors. As caffeine blocks adenosine from binding, it makes us feel more alert and awake.

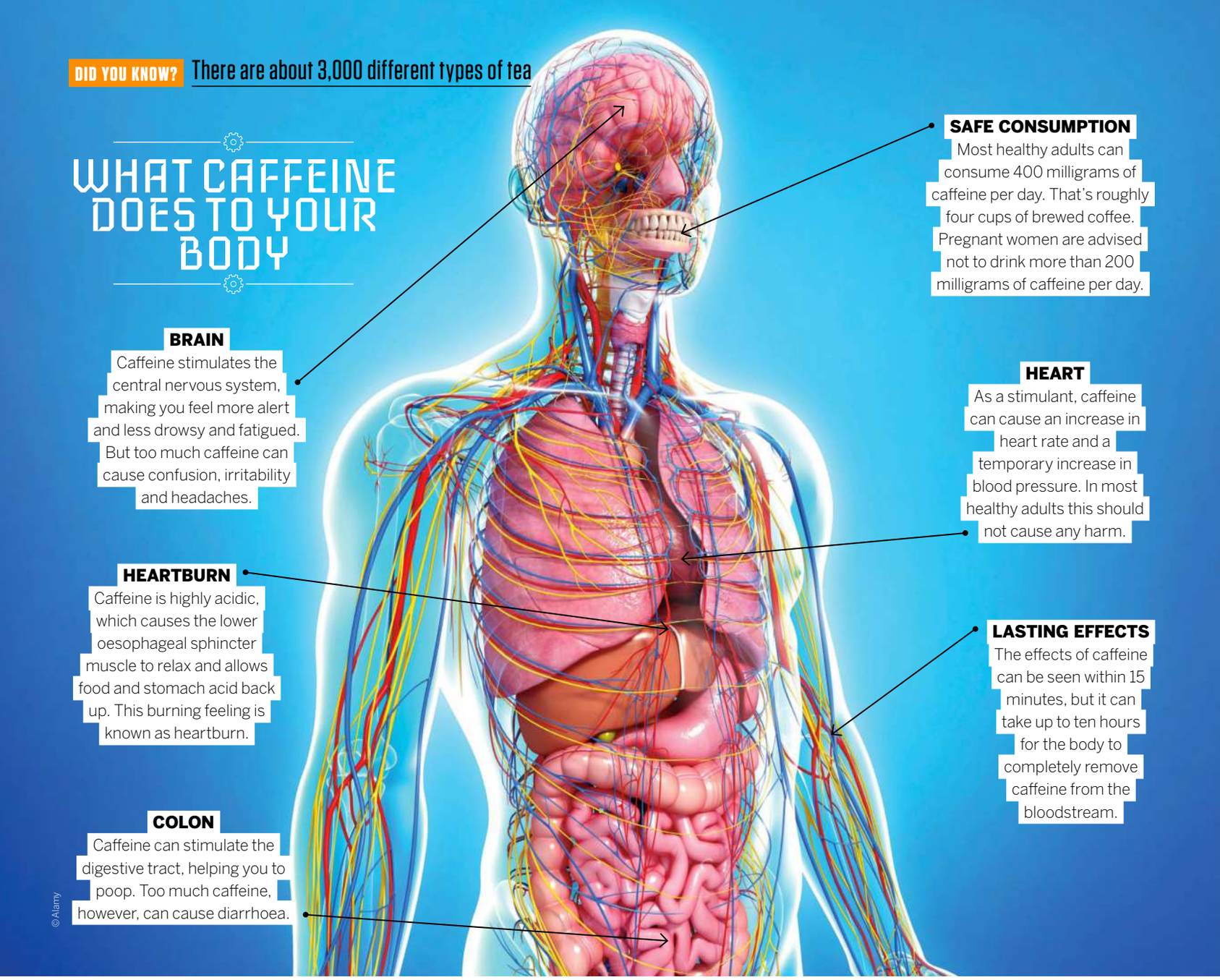
© Alamy

COMMUNICATION
Electrical signals move between two nerve cells as neurotransmitters – chemical messengers in the body – are released and absorbed.

"In its pure state it is a white powder, which can also be added to soft drinks"

DID YOU KNOW? There are about 3,000 different types of tea

WHAT CAFFEINE DOES TO YOUR BODY



BRAIN
Caffeine stimulates the central nervous system, making you feel more alert and less drowsy and fatigued. But too much caffeine can cause confusion, irritability and headaches.

SAFE CONSUMPTION
Most healthy adults can consume 400 milligrams of caffeine per day. That's roughly four cups of brewed coffee. Pregnant women are advised not to drink more than 200 milligrams of caffeine per day.

HEART
As a stimulant, caffeine can cause an increase in heart rate and a temporary increase in blood pressure. In most healthy adults this should not cause any harm.

HEARTBURN
Caffeine is highly acidic, which causes the lower oesophageal sphincter muscle to relax and allows food and stomach acid back up. This burning feeling is known as heartburn.

LASTING EFFECTS
The effects of caffeine can be seen within 15 minutes, but it can take up to ten hours for the body to completely remove caffeine from the bloodstream.

COLON
Caffeine can stimulate the digestive tract, helping you to poop. Too much caffeine, however, can cause diarrhoea.

DECAFFEINATING COFFEE

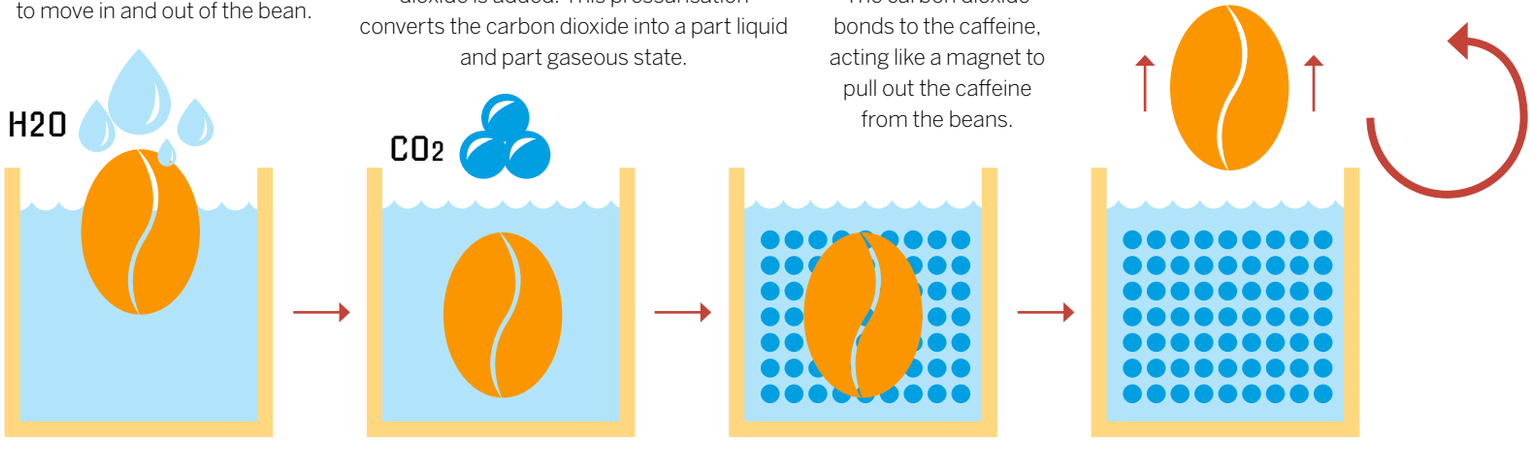
Discover the process that prevents some beans from keeping you up at night

PREPARATION
The beans are first soaked in water to open up their pores. This will allow the caffeine molecules to move in and out of the bean.

PRESSURISATION
The beans are then placed in a stainless-steel extractor, and pressurised liquid carbon dioxide is added. This pressurisation converts the carbon dioxide into a part liquid and part gaseous state.

DECAFFEINATION
The carbon dioxide bonds to the caffeine, acting like a magnet to pull out the caffeine from the beans.

DECAFFEINATED BEANS
After 12 hours, the carbon dioxide gas is removed, leaving the decaffeinated beans in a separate chamber. This process removes 96 to 98 per cent of the caffeine that was originally present in the coffee beans.



INCREDIBLE ICE

We know that it's solid water, but that's just the tip of the iceberg

WORDS **CHARLOTTE HARTLEY**

Our 'blue planet' is famed for its expansive oceans and salty seas, but approximately ten per cent of our planet's surface is frozen over. The vast majority of this ice is found in the polar regions. The Antarctic ice sheet covers an area about the size of the United States and Mexico combined. Meanwhile, in the North Pole, the Greenland ice sheet is so heavy that it presses the land below into a concave bowl shape. Because of its bright-white colouration, ice reflects sunlight back into the atmosphere. This process plays a crucial role in regulating Earth's climate.

But icy worlds also exist beyond our own planet. When NASA's MESSENGER mission glimpsed bright spots at Mercury's poles, scientists theorised that water ice could be hiding inside the planet's deep, sunless craters.

Ice is simply the solid state of liquid water, forming at temperatures of zero degrees Celsius or below. Its chemical composition is two hydrogen atoms bonded to a single oxygen atom – also known as water.

Above main: The islet of Nordaustlandet in the Arctic Circle is covered by large ice caps

Above inset: A glacier is a giant mass of ice that travels slowly over land

When water is cooled to a low temperature, bonds form between different water molecules very easily. This forces water into a crystal lattice structure of many layers of hexagonal rings. Most elements are less compact in their liquid state. However, the unique hexagonal structure of ice crystals is filled with more gaps than the disordered fluid structure of water, meaning ice is about ten per cent less dense than water.

It is this phenomenon that allows ice to float – either in the form of gigantic icebergs travelling across the Arctic Ocean or ice cubes in a refreshing drink on a hot day. In fact, ice's cooling properties are very handy. Before we had electric refrigerators, ice boxes were used to keep food cold and fresh. Ice can also reduce swelling and pain by reducing blood flow to injured body parts.

"Because of its bright-white colouration, ice reflects sunlight back into the atmosphere"

WHY DOES SALT MELT ICE?

When snow is on the horizon, you might have noticed large lorries spreading rock salt on the roads and pavements to prevent them getting slippery. But how does salt get rid of ice?

Icy roads tend to have a thin layer of water covering the ice. This liquid water melts the ice, while the ice simultaneously freezes the water. This balances out so that the amount of water and ice remains constant. But not once you add salt.

Salt is made up of positive sodium and negative chloride ions. These charged particles dissolve in water, disrupting the arrangement of water molecules and making it more difficult for structured ice crystals to form. This lowers the freezing point of water, meaning colder temperatures are required for ice to form. The ice on the ground can no longer freeze the water at zero degrees Celsius. However, the water can still melt the ice. Ultimately, this leads to less ice on the roads.

Tonnes of salt are needed every year to melt snow and ice

DID YOU KNOW? At the peak of the most recent ice age, a 2.2-mile-thick ice blanket covered much of northern Europe and North America

FLUFFY SNOW AND HARD ICE

As snow falls to the ground and forms a pile, tiny pockets of air become trapped in the empty spaces between individual snowflakes. This air gives snow its characteristic fluffiness.

If snow remains on the ground for a few days, more layers can build up. This crushes the lower layers, forcing air out and compacting the snow into a harder texture. If the snow then partially melts, droplets of water fill up the tiny spaces between snowflakes before refreezing into ice crystals. Eventually, almost no air is left inside the frozen layers, leaving a solid sheet of ice.

Snow gets its light and fluffy texture from air trapped between individual snowflakes

THE MICROSCOPIC STRUCTURE OF ICE

Ice and water consist of the same chemical elements, but their molecular structures make them behave rather differently

FLOATING SOLID

Forces of attraction between hydrogen atoms force the molecules into a hexagonal crystal net structure. This open structure means ice is less dense than water, so it floats to the surface.

ICEBERGS

These form when large chunks of ice break off the side of ice shelves, in a process called calving. Icebergs can weigh up to 200,000 tonnes, with most of this mass hidden underwater.

WARM WATER

At warm temperatures, water molecules have lots of energy. They bounce around each other constantly and form weak, transient bonds. There is plenty of space between molecules, making warmer water less dense.

COLD WATER

Colder molecules have little energy and behave sluggishly. They move around more slowly, and stronger bonds can form between them. Cold water is therefore denser, and sinks below warm water.

5 FREEZING FACTS

1 ICE IN SPACE
Far beyond our own Solar System, so-called 'interstellar ice' forms from frozen grains of space dust in dense molecular clouds where new stars are born.

2 BENDY CRYSTALS
Scientists invented a new type of ice that can bend and snap back into shape without breaking. They do this by growing long, single ice crystals in incredibly low temperatures.

3 GLACIAL STORAGE
Over two-thirds of Earth's freshwater is stored in glaciers. Scientists estimate that global sea levels would rise by 80 metres if every glacier and ice sheet melted.

4 ICY ERUPTION
On Enceladus, one of Saturn's moons, 'cryovolcanoes' eject ice instead of magma. Heated ice below the surface erupts as water vapour, turning into ice particles when exposed to the frosty atmosphere.

5 A HUNDRED NAMES FOR ICE
The Alaskan Inupiaq people have over 100 names for different types for ice. We have plenty of words in English, too, including bummock, hummock, floe and pancake ice.

GOLD: THE RICH ELEMENT

How this versatile, unique metal forms, and how it's extracted and used today

WORDS JAMES HORTON

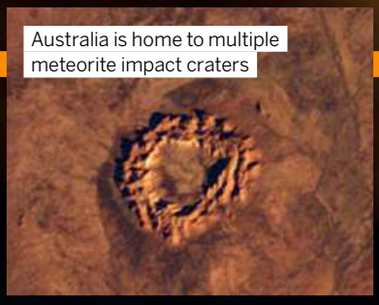
Gold represents a tiny fraction of the elements in the known universe. The reason for its rarity is owed to the incomprehensible amount of energy needed for its formation. Gold is formed within stars, but only in those that are exploding in giant supernovae or incredibly dense ones that have come together in monstrously powerful collisions.

Stars generate energy through the power of fusion, where smaller elements are fused, or combined together into heavier elements. To start with, a star may be mostly hydrogen, the lightest element. The process of fusion under the immense pressure and heat in the star's core will generate helium. When hydrogen runs low and the star begins to reach the next phase of its life cycle, it will fuse helium into the next heavier element, and so on. This process continues until the element iron is made, where the balance suddenly shifts – fusing iron doesn't create energy, it consumes it. With no means of generating internal energy to counteract its own immense pressure and gravity, the star begins to collapse onto itself. If the star is large enough, the result is a supernova – a massive stellar explosion. Heavier elements are formed from the incredible energy generated during this process, including gold.

Very few cosmic events can generate the levels of concentrated energy as within a collapsing aged star, but one that can surpass it is collisions between neutron stars. Neutron stars are small and incredibly dense stars that fell short of becoming black holes. They generate huge gravity and can enter another's orbit. This can result in collisions of enormous magnitudes, generating enough energy to form gold and other heavier metals.

Once flung out into the void of space, gold and other elements slowly came together to form the nexus of our fledgling planet. Over time, as the Earth cooled and separated into layers of core, mantle,and crust, the gold trapped deep within was forced towards the surface. Several theories have been suggested as to how this process occurs, but a shared theme is that heat and pressure forced liquid water up, carrying dissolved gold as it travelled. As the water cooled, the gold precipitated out of solution, forming veins or lodes of concentrated gold.

Over time, some gold travelled through the conduit of water yet further, up to the surface and into rivers. Here small nuggets of gold ran downstream. Perhaps the very first piece was encountered by a fisherman who spied a glint, dipping his hand into the water to recover the chunk of shiny metallic yellow. Thousands of years after this first occurred, gold prospectors and miners would treat gold nuggets in water as a sign of a lode nearby, and they'd busily get to penetrating the ground in search of gold veins to mine. Throughout the history of humanity, many have died for gold, and many have killed for it. But despite that, the story of where gold has taken our species is perhaps not as fascinating as where the element began.



Australia is home to multiple meteorite impact craters

UNEXPECTED FIND

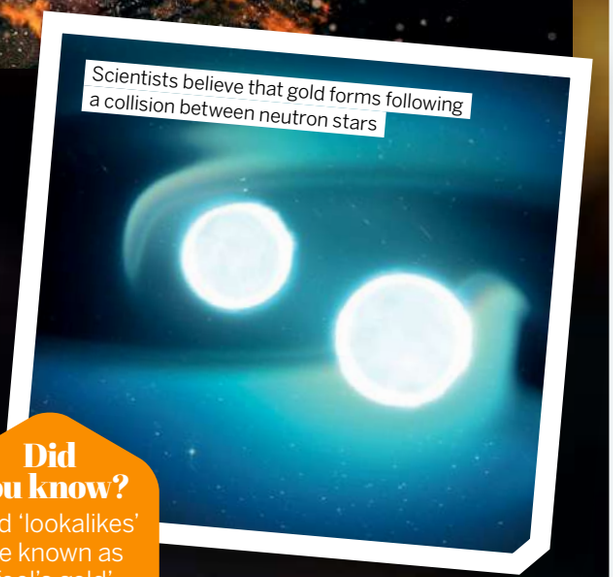
Gold plays a strong role in Australian history. In the late-19th century, so many flocked to the country to take part in its booming 'gold rush' that the population tripled. Owing to pervasive deposits, it's still mined today. However, one company, Evolution Mining, found a different treasure in its hunt for gold. When drilling into the Australian Outback's surface in search of gold deposits, miners instead unearthed sheets of stone that resembled 'shatter cones', which form on the outer rims of impact craters. They followed up this finding with advanced mapping techniques, confirming the uncovering of a three-mile-wide meteorite crater.

"Many have died for gold, and many have killed for it"

Gold's natural purity and attractive colour have captivated human civilisations for thousands of years

DID YOU KNOW? Gold's purity can be measured in karats. 24k gold is entirely pure, but 14k is more common in jewellery

Gold – and other elements heavier than iron – are formed just before stars explode into supernovae



Scientists believe that gold forms following a collision between neutron stars

Did you know?
Gold 'lookalikes' are known as 'fool's gold'

GOLD THROUGHOUT HISTORY

5,000 years ago, the massive Nile River was the key to the ancient Egyptian empire. Its water allowed a bounty of crops to be grown along its edge, keeping its citizens, and its armies, well fed. But there was also a shiny yellow metal that came running down the river: gold. The ancient Egyptians eagerly took this visually appealing treasure, finding that because it was naturally pure and malleable, it required little refinement to be turned into mesmerising decorations. Gold swiftly came to be a symbol, and unit, of wealth, and it has maintained this allure through time and around the globe. Several millennia after the Egyptian pharaohs and their tombs of gold, the Aztec Empire's golden riches were plundered by the conquistadors, who sought the valuable metal for their own. Later still, workers flocked to the western coast of the United States to take part in the California Gold Rush, seeking their own fortunes.

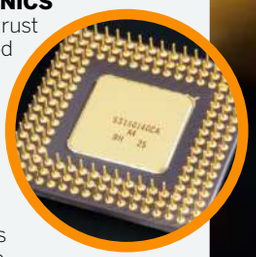
Egyptian pharaoh Tutankhamun's funerary mask was made of gold, and has endured for thousands of years

4 COMMON USES OF GOLD

1 MEDALS AND JEWELLERY

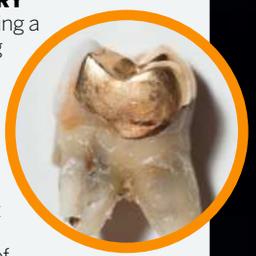
Due to its beautiful colour, its rarity and its malleability, allowing it to be folded into all manner of shapes, gold has been a coveted jewellery material for millennia.

2 ELECTRONICS



Gold doesn't rust and it's a good conductor of electricity, making it a useful item for modern-day electronics. Gold coatings are applied to connectors both for terrestrial uses and for spacecraft.

3 DENTISTRY



As well as being a hard-wearing metal that is pliable and doesn't rust, gold is also non-toxic. This makes it an excellent component of fillings used to fill cavities in dentistry.

4 BULLION

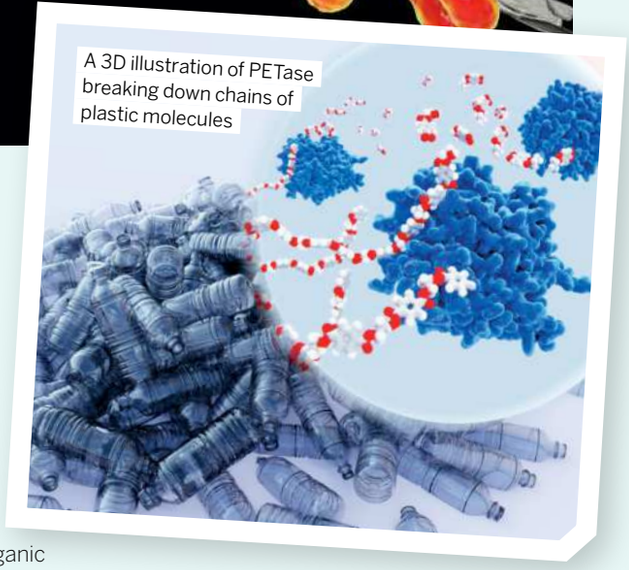
A rare metal that is non-toxic and remains untarnished by rust makes for an ideal medium of wealth exchange. Ancient civilisations used gold within their physical currency as coins, but today wealth is primarily invested into gold by purchasing bullion.

The bacteria *Ideonella sakaiensis* can break down a water bottle

MEET THE PLASTIC-EATING BACTERIA

These tiny organisms could have a massive impact on our environmental plastic problem

WORDS **SCOTT DUTFIELD**



A 3D illustration of PETase breaking down chains of plastic molecules

At least 14 million tonnes of plastic is offloaded into our oceans every year. This pollution has a severe impact on marine ecosystems and can affect human health. Once plastic enters the ocean it can suffocate and entangle animals. Microplastics are also ingested by many marine species that are both preyed upon by other species and that we catch for food. Once ingested, microplastics can leach the toxic contaminants that have collected on their surfaces into the bodies of the organisms that consume it. Those toxins can accumulate and transfer up the food chain from marine life into humans whenever we eat something that has been taken from the sea. On land, the majority of plastic ends up either building up in landfills or being burnt in incinerators, which releases toxic fumes. Just 16 per cent of all plastic produced is recycled to make new plastic.

Did you know?

380 million tonnes of plastic waste is produced each year

However, in 2016 Japanese scientists made a remarkable discovery that could help tackle the world's plastic problem. Having collected plastic bottles outside a recycling facility, scientists discovered that a species of bacteria was 'eating' its way through the bottles. Normally, bacteria spend their time absorbing dead organic matter, but *Ideonella sakaiensis* has developed a taste for a certain type of plastic called polyethylene terephthalate (PET).

After analysing the bacteria, the scientists found that it produced digestive enzymes called hydrolysing PET, or PETase. When these enzymes interact with PET plastic, they break down the long molecular chains into shorter chains (monomers) called terephthalic acid and ethylene glycol. These monomers are then broken down further to release energy for growth of the bacteria.

Following the discovery, many genetic scientists have experimented with *Ideonella sakaiensis* to improve its efficiency. One such research venture has been to genetically engineer bacteria that are more efficient at enzyme production, such as *E. coli*, and turn them into PETase factories. Although the discovery offers hope in the fight against mounting plastic, scientists caution that we are still years away from widespread commercial use. Also, PETase only decomposes PET plastic; there are six other plastic types that we are still unable to degrade using enzymes.

DID YOU KNOW? 80 per cent of all marine debris found on ocean surface water is plastic

BREAKING DOWN PLASTIC

How genetically engineered *E. coli* can work as a PETase factory

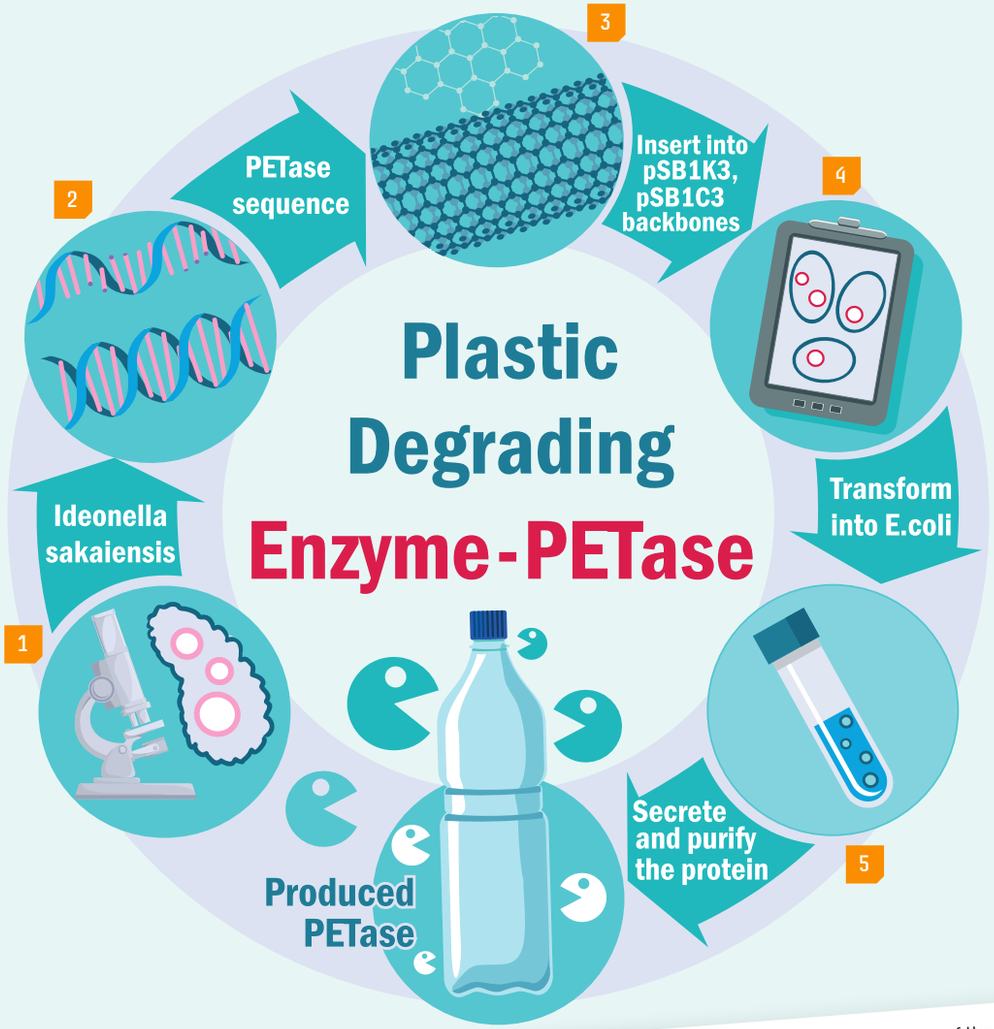
1 *IDEONELLA SAKAIENSIS*
Discovered in Sakai, Japan, in 2016, this bacteria naturally produces enzymes called PETase, which are able to break down plastic.

2 GENETIC EXTRACTION
The portion of genetic information that causes *Ideonella sakaiensis* to make PETase is extracted.

3 DNA CARRIERS
The PETase-coding genetic information is then inserted into a plasmid backbone, a circular sequence of genetic information used in genetic engineering.

4 ENGINEERED *E. COLI*
The plasmid backbone is then inserted into *E. coli* bacteria using either heat or electricity.

5 FARMING
E. coli begin to secrete PETase, which can be collected and purified.



"Scientists have experimented with *Ideonella sakaiensis* to improve its efficiency"

TURNING PLASTIC INTO VANILLA

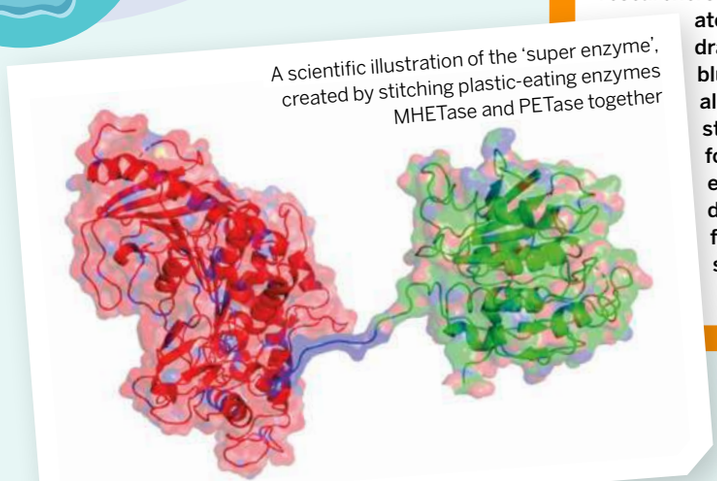
Researchers at the University of Edinburgh have been using *E. coli* bacteria to convert plastic into vanillin, the primary component of vanilla extract. Considering that the global demand for vanillin exceeded 37,000 tonnes in 2018 and that 85 per cent is made from chemicals taken from fossil fuels, using plastic could be an eco-friendly alternative.

After degrading PET plastic into its basic monomers, researchers took the process one step further and converted one of those monomers, terephthalic acid, into vanillin through a series of chemical reactions. The resulting vanillin is believed to be fit for human consumption, though further investigation is needed.

Vanillin, the chemical flavour of vanilla, can be created from degraded plastic

SUPER PETASE

Researchers at the University of Portsmouth have re-engineered PETase to create an enzyme 'cocktail' that they say can digest plastic up to six times faster than normal. The scientists combined PETase with another plastic-eating enzyme called MHETase to form one super enzyme. The combined PETase-MHETase enzyme was created with a synchrotron, a type of particle accelerator that uses X-rays 10 billion times brighter than the Sun. It allowed researchers to see the individual atoms of each enzyme and draw their molecular blueprints, which ultimately allowed researchers to stitch their DNA together to form a super enzyme. This enzyme can also break down polyethylene furanoate (PEF), a sugar-based bioplastic.



A scientific illustration of the 'super enzyme', created by stitching plastic-eating enzymes MHETase and PETase together

SPACE

36 **Could we build the USS Enterprise?**
Discover the real-world and theoretical technologies of Star Trek's flagship spacecraft

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Why do the eight planets of the Solar System orbit on the same plane?

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This lunar spacecraft is being developed for a future human colony on the Moon

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Journey into a star's habitable zone, where temperatures allow liquid water to exist

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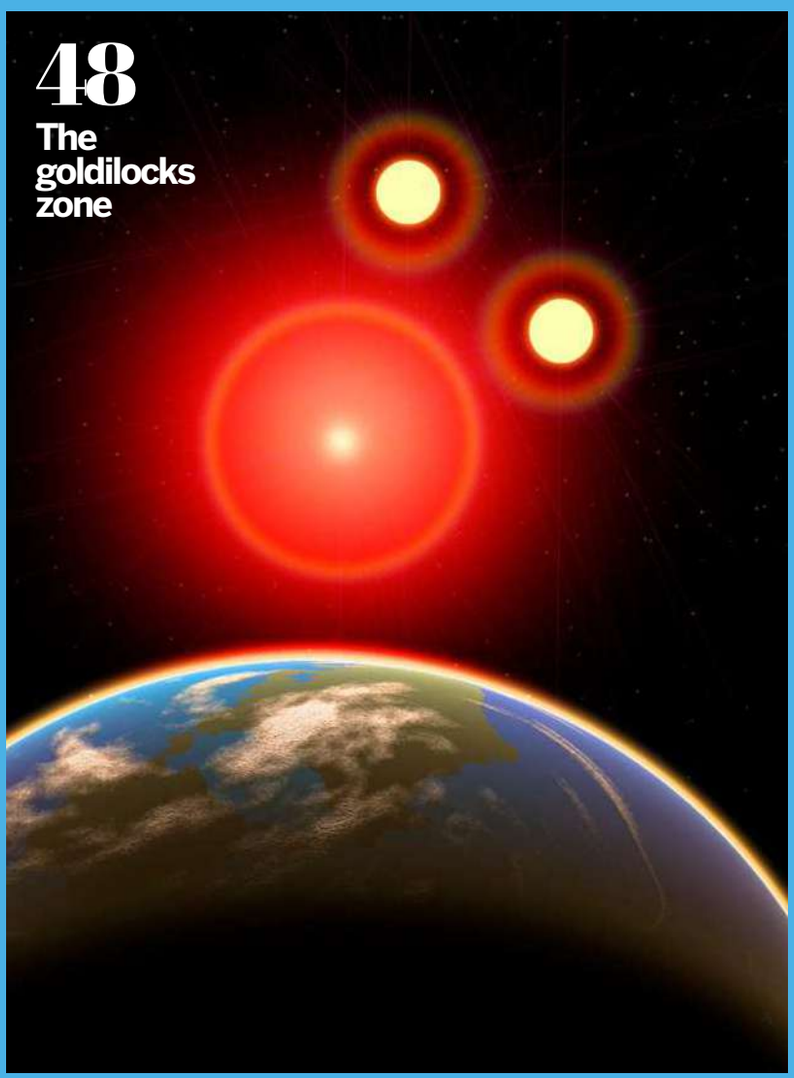
What information did the Voyager spacecraft carry into space?



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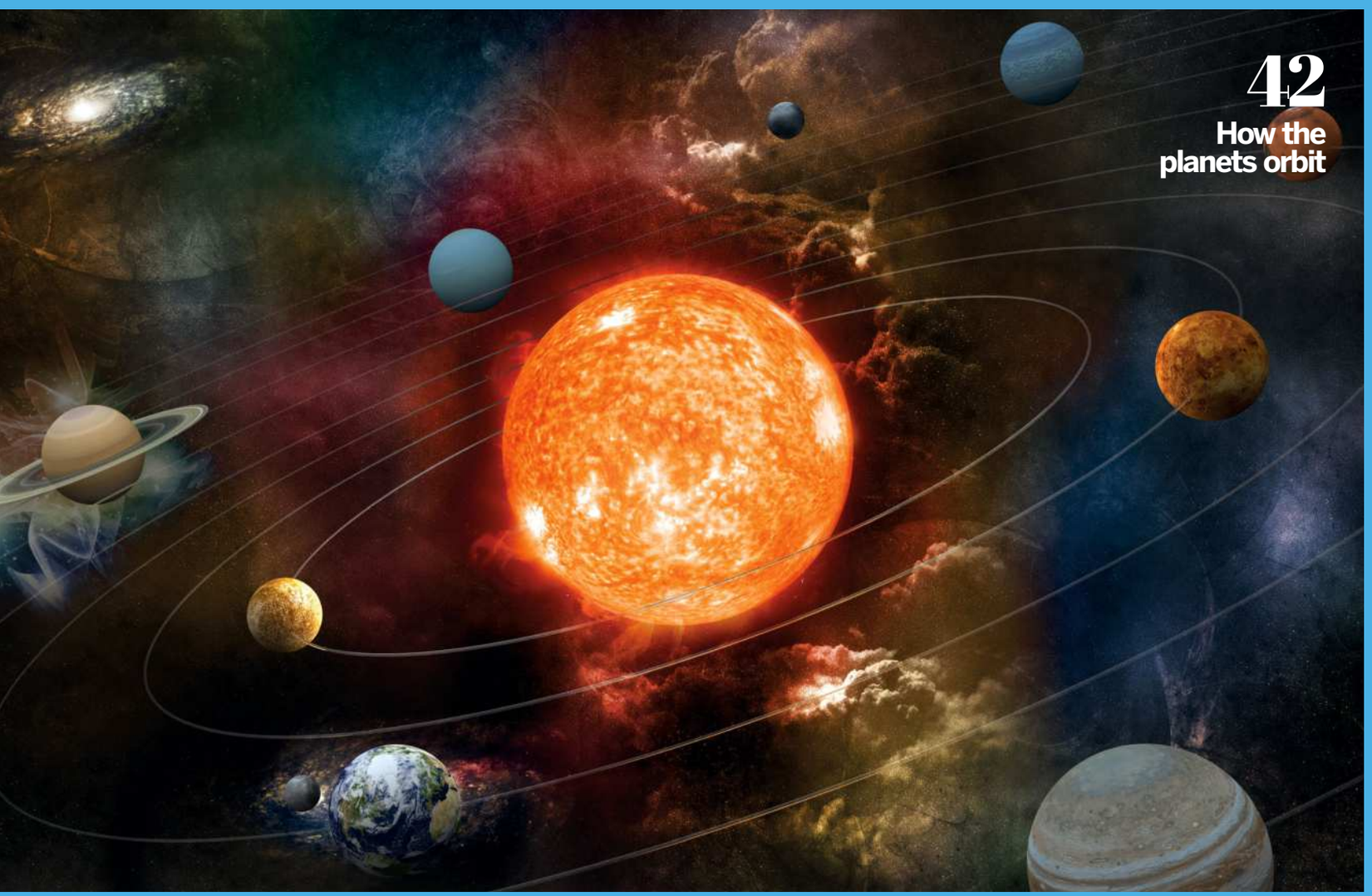
Could we build the USS Enterprise?



42
How the planets orbit


NCC-1701

COULD WE BUILD THE USS ENTERPRISE?

Discover the real-world and theoretical technologies of *Star Trek*'s flagship spacecraft

WORDS **SCOTT DUTFIELD**

Launched into space from the mind of creator Gene Roddenberry in the 1960s, the USS Enterprise NCC-1701 was the very first *Star Trek* spacecraft to reach warp speed on television screens around the world. The ultra-fast, near-invisible and sometimes-time-travelling Constitution-class starship was the most advanced spacecraft at the time of its launch in fictional 2245. Built in space, the Enterprise is a feat of make-believe engineering. It's estimated that the spacecraft would weigh more than 4 million tonnes and house a crew of 430. In comparison, the heaviest human-made object to venture into space is the International Space Station (ISS), which has a mass of around 419 tonnes. China is reportedly researching the possibility of constructing a colossal spacecraft measuring up to 0.6 miles in length – this would absolutely dwarf the ISS, which is only 110 metres long.

Engineers still have 233 years to achieve Roddenberry's vision for space exploration, and several scientific breakthroughs suggest that we might be heading towards a spaceship that's reminiscent of the Enterprise. As a Constitution-class Starfleet Federation starship, the main role of the Enterprise is to venture on intergalactic exploration and diplomatic missions. To assist the crew on their journeys of discovery, the ship is equipped with an array of advanced scanners and sensors.

Before descending upon a new world, the crew aboard the Enterprise flipped a few switches and scanned the planet below for signs of life. It's a pretty handy gadget to have when searching for new life, but one that seems unrealistic. However, scientists are one step closer to making this technology a reality.

Researchers have discovered that the biochemistry of all life forms interacts with light in a way that inorganic or artificial materials don't. For example, when light hits the long chains of carbon molecules that make up amino acids – the building blocks of proteins – it becomes circularly polarised. This means that it travels in either clockwise or anticlockwise spirals. Scientists could theoretically observe and identify this light interaction in the hope of discovering new life forms from the observatories on spacecraft, such as from future space-based telescopes like the Large Ultraviolet Optical Infrared Surveyor (LUVOIR).

Did you know?

Robert April was the first captain of the USS Enterprise

Enterprise overlooking a planet

FUELLING THE FUTURE

How to make a spaceship move faster than the speed of light

One of the most iconic abilities of the USS Enterprise is its ability to zip from one end of the galaxy to the other in mere moments using its fictitious warp drive. Human technology is currently nowhere near advanced enough to replicate the Enterprise's warp drive. However, the theory behind building one has been around since the early 1990s. To achieve speeds faster than the speed of light, physics' natural speed limit, theoretical physicist Miguel Alcubierre proposed that we must bend the fabric of space-time.

Space-time can be imagined as a sheet of rubber on which all matter sits, creating dips in the rubber relative to their masses. Alcubierre proposed that if space-time could be folded in front of a spaceship and then expanded behind it, the ship could travel much faster than the speed of light, achieving 'warp speed'. This bending of space-time would theoretically continue to move in a wave and act as a conveyor belt, carrying the spaceship along it.

To achieve such space-time manipulation, Alcubierre suggested an enormous amount of negative mass, a phenomenon rarely created in laboratories and seen as vacuum energy in space. The amount of negative mass needed to facilitate Alcubierre's warp drive would have to be equivalent to the mass of a huge star, distributed in a ring around a spacecraft. This hypothetical ring of negative mass would create a 'warp bubble', which would distort space-time and transport any spacecraft within it.

Did you know?

More than 600 people have ventured into space

Although Alcubierre's theory requires negative mass, recent research out of Göttingen University, Germany, offers a new area of physics for researchers to explore potential for warp power. In 2021, physicist Erik Lentz hypothesised that positive mass and energy could also provide the necessary requirements to construct a warp bubble. Instead of the solid ring of negative mass detailed in Alcubierre's theory, Lentz proposes that layering rings of extremely dense fluid, similar to the composition of a neutron star's interior, would yield the same result. With the ability to bend space-time, those inside the warp bubble could travel through space faster than the speed of light without breaking any physics laws. Much like the ability to walk freely in an aeroplane, a warp bubble would theoretically allow a spaceship and its crew to move around without feeling the effects of warp speed.

But there are several questions that remain unanswered about building a real-life warp-capable vessel, such as how to control its direction and distance, as well as how a ship would exit a warp bubble. In *Star Trek*, to fuel the warp drive and create enough energy to bend space-time, the USS Enterprise takes advantage of the annihilation reaction between matter – in the form of deuterium, a real-world isotope of hydrogen – and antimatter, which is regulated by a fictional crystal called dilithium. The 'electro-

WORMHOLE ALTERNATIVE

Rather than turning the very fabric of space-time into an intergalactic conveyor belt, hopping through a wormhole might be an easier alternative. Despite their existence being predicted by Albert Einstein, researchers still aren't sure if they really exist. In a nutshell, a wormhole is a tunnel that connects two openings in folded space-time. Entering at one end would theoretically see you shoot out the other end much faster than the speed of light travels, having travelled a tremendous distance. The only trouble is that we just don't know how it would work, and we aren't even close to creating an artificial wormhole. Scientists are looking throughout the Milky Way, inside black holes and even in fluctuations of space-time called quantum foam for wormholes, and thus far they've turned up empty handed. The sooner one is discovered and studied, the closer we might be to using them as space-time highways.

DID YOU KNOW? The most distant spacecraft from Earth is around 14.5 billion miles away

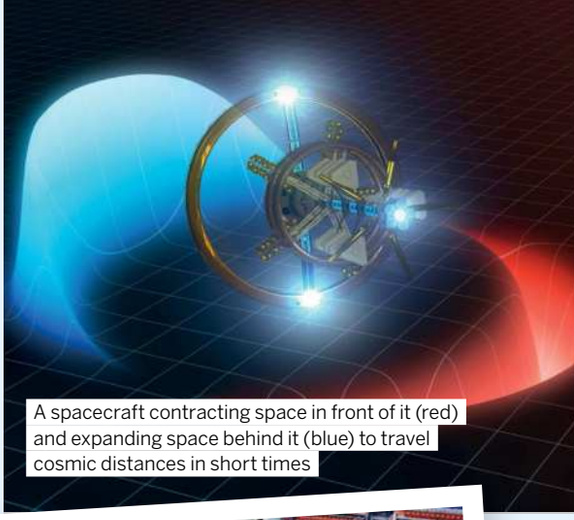
plasma' energy released from this reaction creates the necessary warp bubble to manipulate space-time and move the ship. The biggest hurdle to overcome in using annihilation reactions for energy is producing enough antimatter to power a warp drive.

As the name suggests, antimatter is a mirrored and opposing version of normal matter. For example, an electron has a negative charge, so its antimatter partner has the same mass but an opposite positive charge, called a positron. In order to create antimatter, particle accelerators such as the Large Hadron Collider fire high-speed particles at one another to release antimatter.

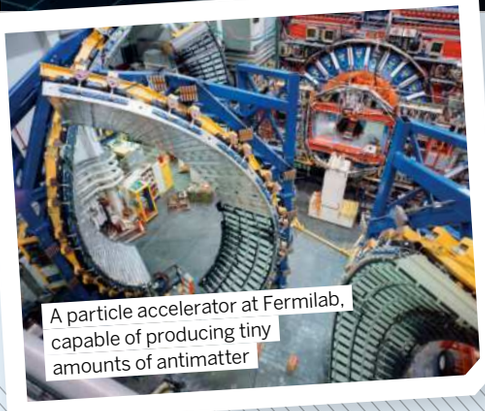
> "Despite quantum woes, research into antimatter spacecraft is still ongoing"

However, there are several physical issues with using antimatter as a fuel source. Firstly, the yield of its production is very low. The Fermi National Accelerator Laboratory (Fermilab) can only produce enough antimatter in an hour to power 1/1000th of a watt, and therefore 100,000 Fermilabs would be required to power a single light bulb. Due to the fact that antimatter annihilates when it comes in contact with regular matter, storing it is near impossible, as everything is made up of matter.

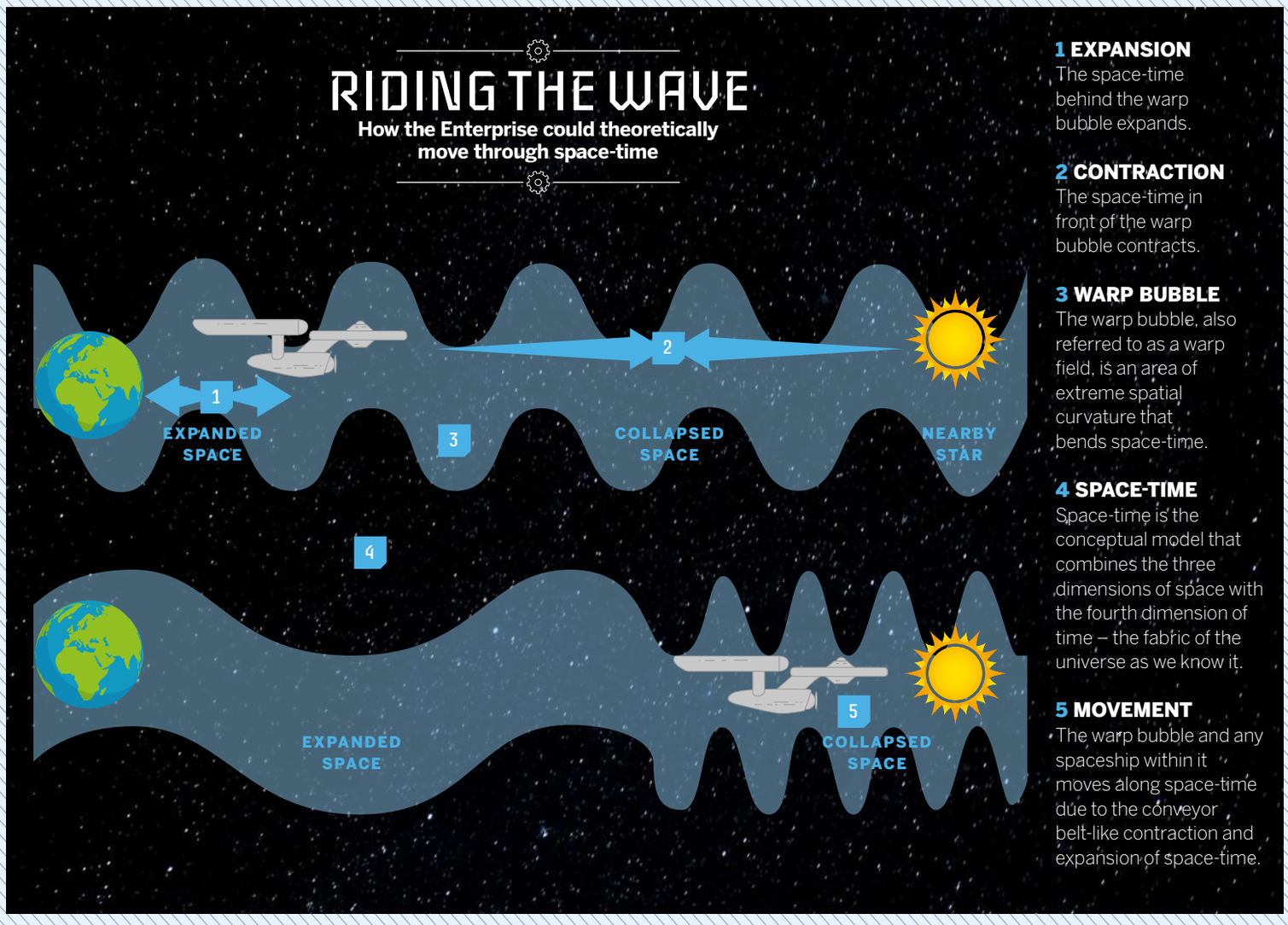
Despite these quantum woes, research into antimatter spacecraft is still ongoing. One of the latest advancements in antimatter propulsion is NASA's proposal for a space probe that will travel all the way across our stellar neighbourhood to a relatively nearby star 4.2 light years away called Proxima Centauri, which will be done using an annihilation accelerator. But until scientists can successfully mass produce and store antimatter, powering a spacecraft that resembles the Enterprise remains firmly in the realm of science fiction.

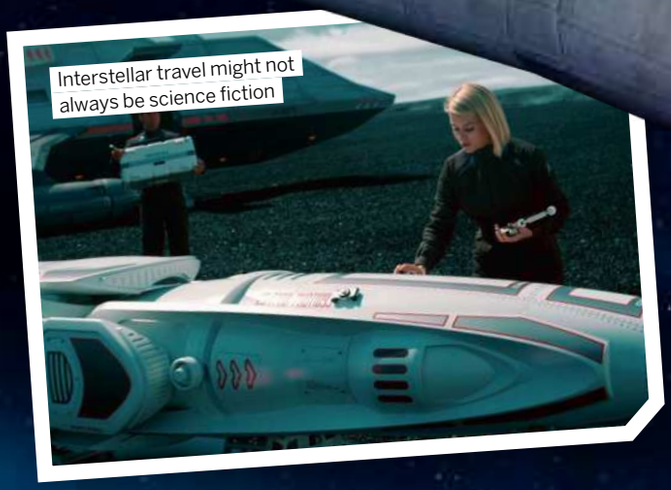


A spacecraft contracting space in front of it (red) and expanding space behind it (blue) to travel cosmic distances in short times



A particle accelerator at Fermilab, capable of producing tiny amounts of antimatter





ALL ABOARD THE USS ENTERPRISE

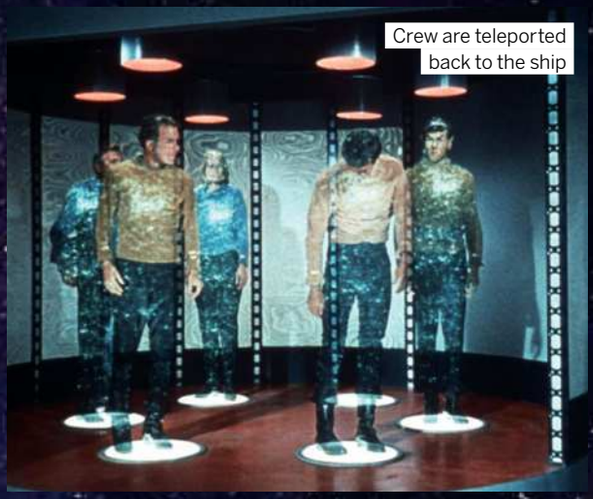
How this Star Fleet spaceship could be brought to life with real world technology

1 DEFLECTOR
Fending off enemy lasers and withstanding space radiation is an everyday task for the Enterprise. But thanks to the ship's all-encompassing deflector shield, it can withstand such attacks. The closest scientists have gotten to replicating any sort of shielding technology that could protect future spacecraft involves generating a protective electromagnetic field. Much like how Earth shields itself from solar radiation, researchers have found a way to replicate a similar shield against radiation in the laboratory, but its spacecraft applications remain unclear.

2 HULL
The spacecraft's hull and body are composed of material made from a fictitious element stronger than diamonds, called tritanium. Its durable properties allow the starship to withstand immense changes in temperature. It's unyielding to the force of warp speed and protects the crew against space radiation. In the absence of tritanium in the real world, engineers heavily rely on aluminium to build spacecraft due to its strong-but-lightweight properties. Some research suggests that plastic could be used as an alternative material to withstand the pressures of space travel.

3 SICKBAY
As the medical hub for the Enterprise, the sickbay is filled with healing and sensory technology unlike anything seen in the real world, including medical tricorders. These handheld devices simply scan a patient to reveal any illnesses or injuries. Scientists are closer to this feat of medical engineering with the creation of DxtER, a high-tech device which can detect 34 different medical conditions, including diabetes, pneumonia and tuberculosis, using Bluetooth sensors.

DID YOU KNOW? There have been nine different USS Enterprise spacecraft in both film and television


Crew are teleported back to the ship

Did you know?
There are 10^{82} atoms in the observable universe

4 PHOTON TORPEDOES

The Enterprise is equipped with 250 deadly photon torpedoes, with these making up its heavy-hitting artillery. Similar to the way the *Star Trek* writers created an annihilation reaction-fuelled warp drive, a photon torpedo uses the same reaction to cause an explosion upon impact with enemy ships. However, like the warp drive, real-world versions of these weapons face the same physical hurdles.

5 TELEPORTER

"Beam me up, Scotty" is commonly heard in the transporter room as Captain Kirk and his crew teleport off the Enterprise onto some distant land. As for replicating the technology, scientists have successfully achieved teleportation in laboratory experiments, but only on a quantum level. A 2020 study found that researchers could 'teleport' data over a distance of 27 miles. As for human teleportation, the science of reconstructing all the atoms in our bodies and reconstructing them in the exact order remains science fiction.

6 ANTIGRAVITY

Aboard the starship Enterprise, the crew can freely walk around the vessel under the normal gravitational conditions we experience on Earth. This is achieved with gravity plates that line the ship's hull and interior floors, which are able to create an artificial gravity field aboard the ship. Artificial gravity is continually examined by engineers for advancements in space travel, with several suggestions made, like using magnets and electricity to replicate gravity or even constructing a ship that spins to exploit the force of inertia and create artificial gravity.

AR zone
SCAN HERE

HOW THE PLANETS ORBIT

Why do the eight planets of the Solar System orbit on the same plane?

WORDS JOANNA WENDEL

DID YOU KNOW? The gravity on Jupiter is two-and-a-half times greater than on Earth

If you've ever gazed at a model of the Solar System, you've likely noticed that the Sun, planets, moons and asteroids sit roughly on the same plane. But why is that? To answer this question, we have to travel to the very beginning of the Solar System, about 4.5 billion years ago. Back then, the Solar System was just a massive, spinning cloud of dust and gas. That massive cloud measured 12,000 astronomical units (AU) across. A single astronomical unit is the average distance between Earth and the Sun, or about 93 million miles. The cloud became so big that even though it was just filled with dust and gas molecules, it started to collapse and shrink under its own mass.

As the spinning cloud of dust and gas started to collapse, it also flattened. Imagine a pizza maker throwing a spinning slab of dough into the air. As it spins, the dough expands, but becomes increasingly thin and flat. That's what happened to the very early Solar System. Meanwhile, in the centre of this ever-flattening cloud, all those gas molecules got squeezed together so much that they heated up.

Under the immense heat and pressure, hydrogen and helium atoms fused, kick-starting a nuclear reaction in the form of a baby star: the Sun. Over the next 50 million years, the Sun continued to grow, collecting gas and dust from its surroundings and burping out waves of intense heat and radiation. Slowly, the growing Sun cleared out a doughnut of empty space around it.

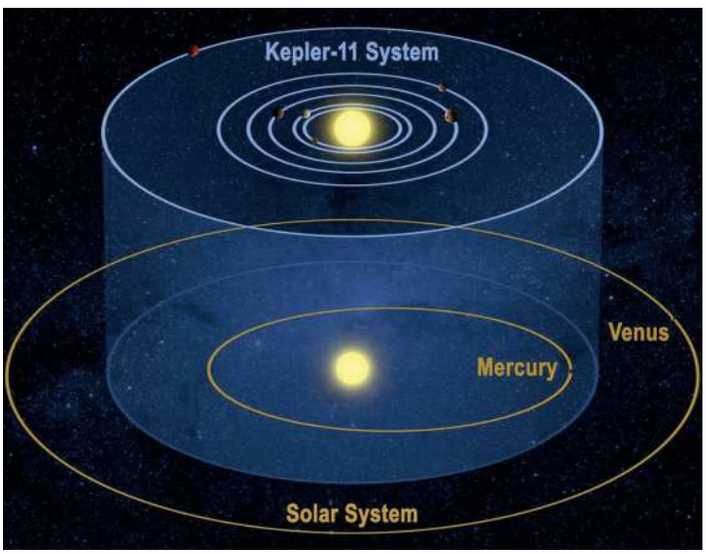
As the Sun grew, the cloud continued to collapse, forming a disc around the star that became ever flatter and continued to expand, with the Sun at the centre. Eventually, the cloud became a flat structure called a protoplanetary disc, orbiting around the young star. The disc stretched hundreds of AU across and was just one-tenth of that distance thick. For tens of millions of years thereafter, the dust particles in the protoplanetary disc gently swirled around, occasionally knocking into each other. Some even stuck together. Over those millions of years, the particles became millimetre-long grains, those grains became centimetre-long pebbles and the pebbles continued to collide and stick together.

Did you know?
Saturn is so light it could float on water

Eventually, most of the material in the protoplanetary disc stuck together to form huge objects. Some of those objects grew so big that gravity shaped them into spherical planets, dwarf planets and moons. Other objects became irregularly shaped, like asteroids, comets and some smaller moons. Despite the objects' different sizes, they stayed more or less on the same plane where their building materials originated. And that's why the Solar System's eight planets and other celestial bodies orbit on roughly the same level.

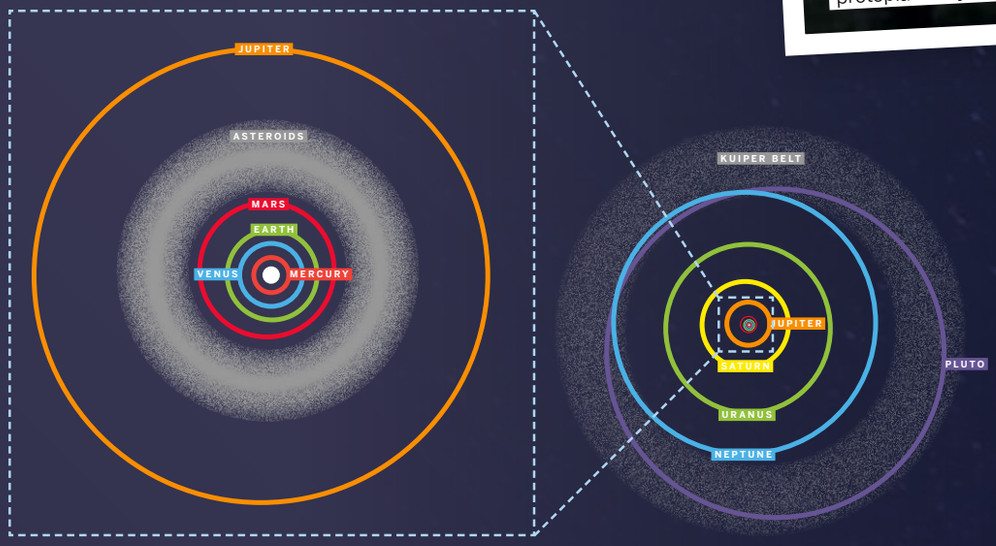
SIMILAR SYSTEMS

Our Solar System isn't unique. There are more than 3,200 stars in the Milky Way known to have planets orbiting them. One of the 'closest' examples is over 2,000 light years away from Earth: the Kepler-11 planetary system. Kepler-11 is the system's central star – a yellow dwarf star which is similar in size to the ice giants Uranus and Neptune. There are six known planets in this system, all of which orbit much closer to their star than most of the planets in our Solar System. The closest is Kepler-11b, which is around ten times closer to Kepler-11 than Earth is to the Sun. The outermost planet is Kepler-11g, orbiting its star from around 43 million miles away, which would place it between Mercury and Venus in our Solar System.



ORBITING THE SUN

How the major bodies move through the Solar System




A newly formed star surrounded by a swirling protoplanetary disc of dust and gas

PRESSURE RISES

Pressure built up within this collapsing nebula, causing hydrogen atoms at the centre to transform into helium by nuclear fusion. This resulted in the release of massive amounts of energy.

2

BUILDING BLOCKS

Around 99.8 per cent of the material fell into the centre of the cloud, forming the Sun; the remaining matter formed the Solar System as we know it.

3

4

A NEW STAR

A protostar formed in the centre. Minerals and metals began to clump together under the gravity of the newly formed star.

MERCURY

DISTANCE FROM SUN: 35 million miles

ONE ORBIT: 88 Earth days

ORBITAL VELOCITY: 107,082 miles per hour

VENUS

DISTANCE FROM SUN: 67 million miles

ONE ORBIT: 225 Earth days

ORBITAL VELOCITY: 78,337 miles per hour

EARTH

DISTANCE FROM SUN: 93 million miles

ONE ORBIT: 365 Earth days

ORBITAL VELOCITY: 66,615 miles per hour

MARS

DISTANCE FROM SUN: 142 million miles

ONE ORBIT: 687 Earth days

ORBITAL VELOCITY: 53,853 miles per hour

JUPITER

DISTANCE FROM SUN: 484 million miles

ONE ORBIT: 11.86 Earth years

ORBITAL VELOCITY: 29,236 miles per hour

SATURN

DISTANCE FROM SUN: 887 million miles

ONE ORBIT: 29.46 Earth years

ORBITAL VELOCITY: 21,675 miles per hour

URANUS

DISTANCE FROM SUN: 1.8 billion miles

ONE ORBIT: 84 Earth years

ORBITAL VELOCITY: 15,233 miles per hour

NEPTUNE

DISTANCE FROM SUN: 2.8 billion miles

ONE ORBIT: 164.8 Earth years

ORBITAL VELOCITY: 12,146 miles per hour

PLUTO

DISTANCE FROM SUN: 3.7 billion miles

ONE ORBIT: 248.6 Earth years

ORBITAL VELOCITY: 10,603 miles per hour

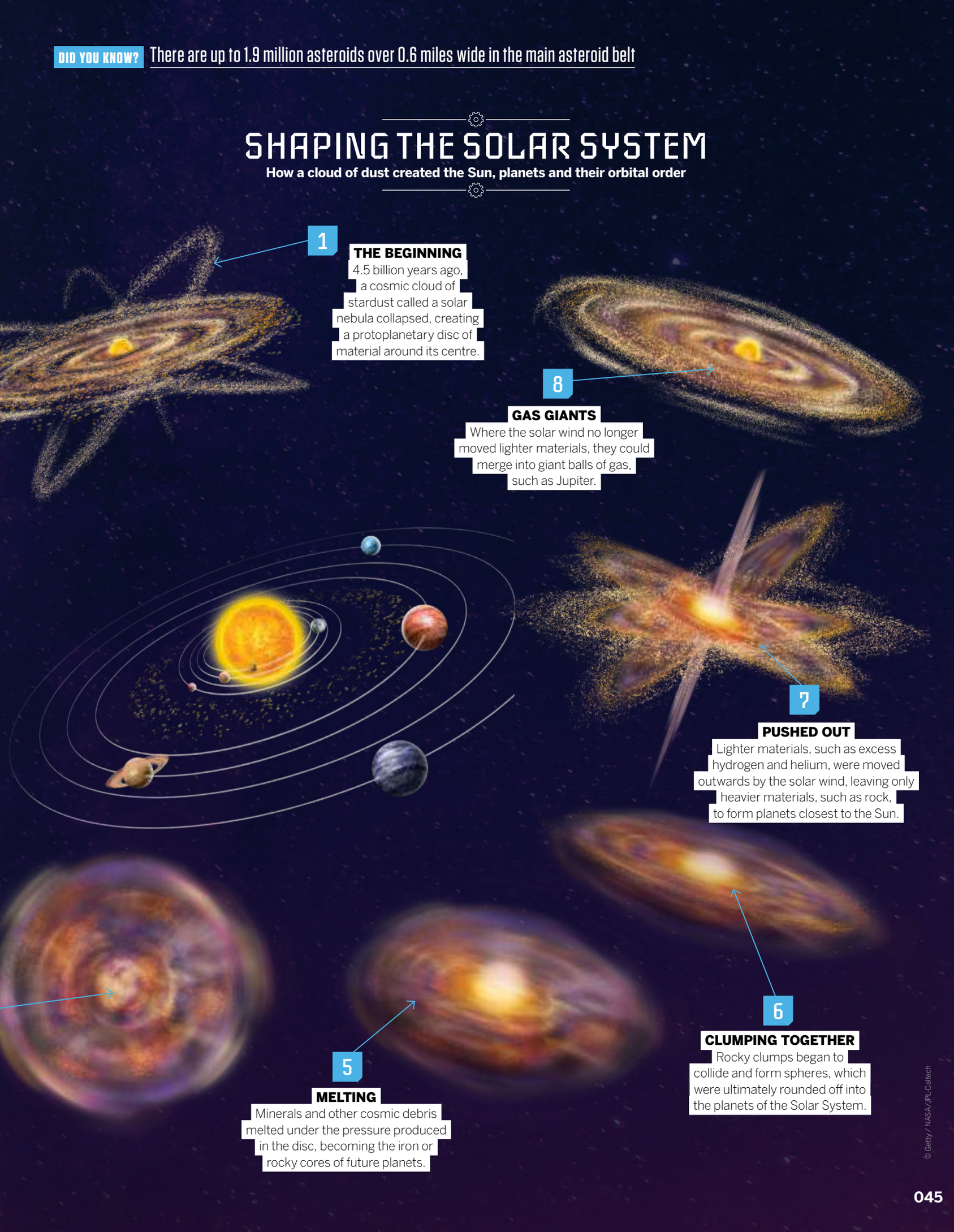
Did you know?

The Sun is one of over 100 billion stars in the Milky Way

DID YOU KNOW? There are up to 1.9 million asteroids over 0.6 miles wide in the main asteroid belt

SHAPING THE SOLAR SYSTEM

How a cloud of dust created the Sun, planets and their orbital order



1

THE BEGINNING
4.5 billion years ago, a cosmic cloud of stardust called a solar nebula collapsed, creating a protoplanetary disc of material around its centre.

8

GAS GIANTS
Where the solar wind no longer moved lighter materials, they could merge into giant balls of gas, such as Jupiter.

7

PUSHED OUT
Lighter materials, such as excess hydrogen and helium, were moved outwards by the solar wind, leaving only heavier materials, such as rock, to form planets closest to the Sun.

6

CLUMPING TOGETHER
Rocky clumps began to collide and form spheres, which were ultimately rounded off into the planets of the Solar System.

5

MELTING
Minerals and other cosmic debris melted under the pressure produced in the disc, becoming the iron or rocky cores of future planets.

INSIDE THE BLUE MOON LANDER

This lunar spacecraft is being developed for a future human colony on the Moon

Did you know?

Jeff Bezos founded Blue Origin in 2000

WORDS **AILSA HARVEY**

To date, 12 astronauts have walked on the lunar surface. While nobody has set foot on its surface since 1972, plans are in place to return people to the Moon soon. But some are envisaging steps much further ahead, including establishing a human colony on the Moon. In order to increase our knowledge of the Moon and carry out experiments on its surface, people and machinery first need to be delivered there by lunar landers. One of these currently under development is the Blue Moon lander, created by privately funded aerospace manufacturer Blue Origin. The company, which also focuses on space tourism, is owned by Jeff Bezos. Blue Moon wasn't selected for NASA's Artemis Moon missions, but Blue Origin hopes to use the lunar lander in future missions to achieve a sustained human presence in space.

The Blue Moon lander, which entered development in 2016, uses autonomous technology to land with high precision. Equipped with lidar (light detection and ranging) sensors, Blue Origin claims that its craft is guaranteed to land within 23 metres of the preplanned landing site. Scanning the Moon, laser beams are fired at its surface to create a computerised image of the terrain. This prevents the lander from descending onto hazards and allows the flattest nearby surface to be chosen.

When in lunar orbit, the lander can release microsatellites into space. Once on the Moon, the lander will release other apparatus, such as rovers, from its top deck. The equipment that's attached to the lander can be altered based on specific mission requirements. For Blue Moon landers with a human crew – and those returning equipment and lunar samples to Earth – an ascent module can be added. This launches from the Moon to travel back to Earth.

Bezos during a talk about Blue Moon at the Walter E. Washington Convention Center

HOW THE SPACECRAFT FUNCTIONS

Blue Moon can deliver a wide range of equipment to the Moon

LOWERING SYSTEM
A crane system lowers the payload down onto the lunar surface.

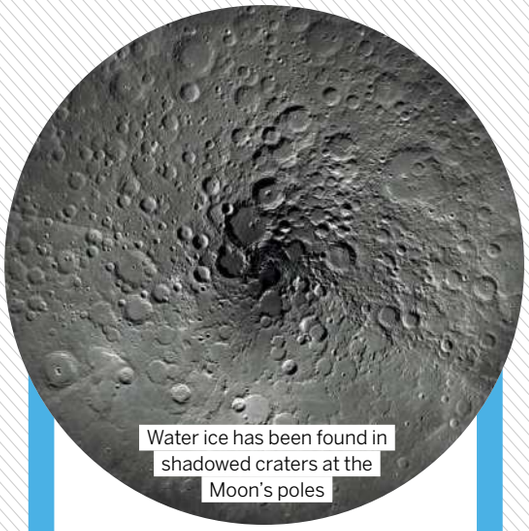
LANDING PADS
The landing pads are smaller than previous designs as the Moon's surface is now known to be solid enough to support the lander's weight.

LONG LEGS
The lander is designed with significant clearance under the body to avoid lunar obstacles.

DID YOU KNOW? Engineers began work on Blue Moon in 2016, but it wasn't revealed until 2019

NASA aims to return humans to the Moon by 2024 at the earliest

Blue Moon can land on inclines of up to 15 degrees



Water ice has been found in shadowed craters at the Moon's poles

REFUELLING IN SPACE

The Blue Moon lander uses liquid hydrogen as fuel. This propellant was chosen with future possibilities in mind. Scientists now know that there is water ice on the Moon, from which hydrogen can be extracted. By using this common element to power the lander, Bezos hopes that one day the spacecraft can be refuelled in space, utilising the Moon's natural water resources. While speaking at the JFK Space Summit in Massachusetts, Bezos said: "We know one day we'll be refuelling that vehicle on the surface of the Moon."

When separating water into its component elements by breaking its chemical bonds with thermal, electrical or chemical energy, oxygen is released. This oxygen could be used to combine with rocket fuel for combustion, or used for human breathing apparatus in space. Unlike aeroplanes, spacecraft like the Blue Moon lander can't compress fresh air from their surroundings to breathe in the cabin, so they need to carry their own supply. Making this on the Moon means the lander only needs to carry half as much oxygen during a flight to the Moon.

EXPLORATION ROVERS
The lander can carry up to four large rovers at the same time.

LANDER SIZE
With its legs fully extended, Blue Moon stands at four metres.

SPHERICAL TANK
When the fuel tank is full, the lander weighs 15,000 kilograms.

ROCKET ENGINE
The BE-7 is a flexible high-performance rocket engine.

Blue Origin has also designed a crewed alternative to Blue Moon

THE GOLDILOCKS ZONE

Journey into a star's habitable zone, where planetary temperatures allow liquid water to exist

WORDS ANDREW MAY

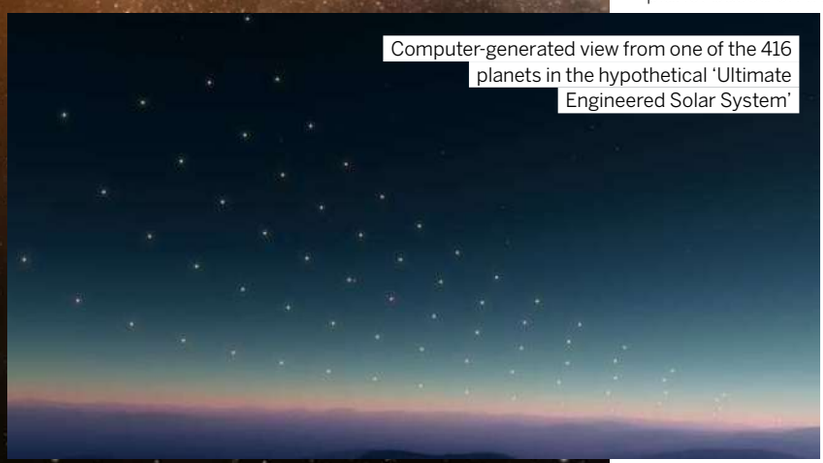
DID YOU KNOW? Special conditions, such as Europa's subsurface ocean, can allow water to exist outside the habitable zone

In the fairy tale, Goldilocks is a fussy little girl whose porridge has to be just right, neither too hot nor too cold. It's the same with life itself – or at least the kind of water-based life we're familiar with on Earth. A planet has to be just right: neither so cold that water only exists as frozen ice, nor so hot that it all boils away. That's not going to be true of all the planets orbiting a star, just those within a certain range of orbits dubbed the 'Goldilocks zone', or more formally the 'habitable zone'. If a planet's orbit takes it too close to its parent star then it will be too hot for liquid water to exist, and if it's too far out it will be too cold. That's obvious enough, but the actual distances involved, which define the boundaries of the habitable zone, will vary from star to star.

Our Sun is a G-type yellow dwarf, and there's no doubt where its habitable zone lies because Earth – orbiting around 93 million miles away – is within it. But for M-type red dwarfs, which are smaller and cooler than the Sun, the habitable zone lies much closer to the star. And for a larger, hotter, A-type star like Sirius, the Goldilocks zone is further out.

For astrobiologists, the people who search for life on other planets, being in the habitable zone is just one of the factors they have to think about. Take our Moon, for example. It obviously lies in the Goldilocks zone because it's so close to Earth, yet there's no liquid water on its surface. That's because atmospheric pressure and composition also have to be taken into account. This makes the Moon, which has no atmosphere to speak of, a non-starter. It's also important not to read too much into the word 'habitable'. Even if conditions on a planet are exactly right for the existence of liquid water, this doesn't necessarily mean it's inhabited. Scientists haven't yet worked out exactly how life first arose here on Earth, so we don't know what other subtle ingredients are necessary in addition to water and an atmosphere.

Our own Solar System is the best studied of all planetary systems. Theoreticians have worked out where its Goldilocks zone ought to be by estimating the surface temperature of a planet based on the amount of solar heating it receives. Reassuringly, the results agree with what we know from observations. The Earth – a very watery planet that's teeming with life – is situated comfortably inside the habitable zone. Mars, which seems to have had plenty of water in the past but is a barren desert today, is right on its outer edge. And at the inner edge is Venus – a boiling-hot planet thanks to both its proximity to the Sun and its super-thick atmosphere.



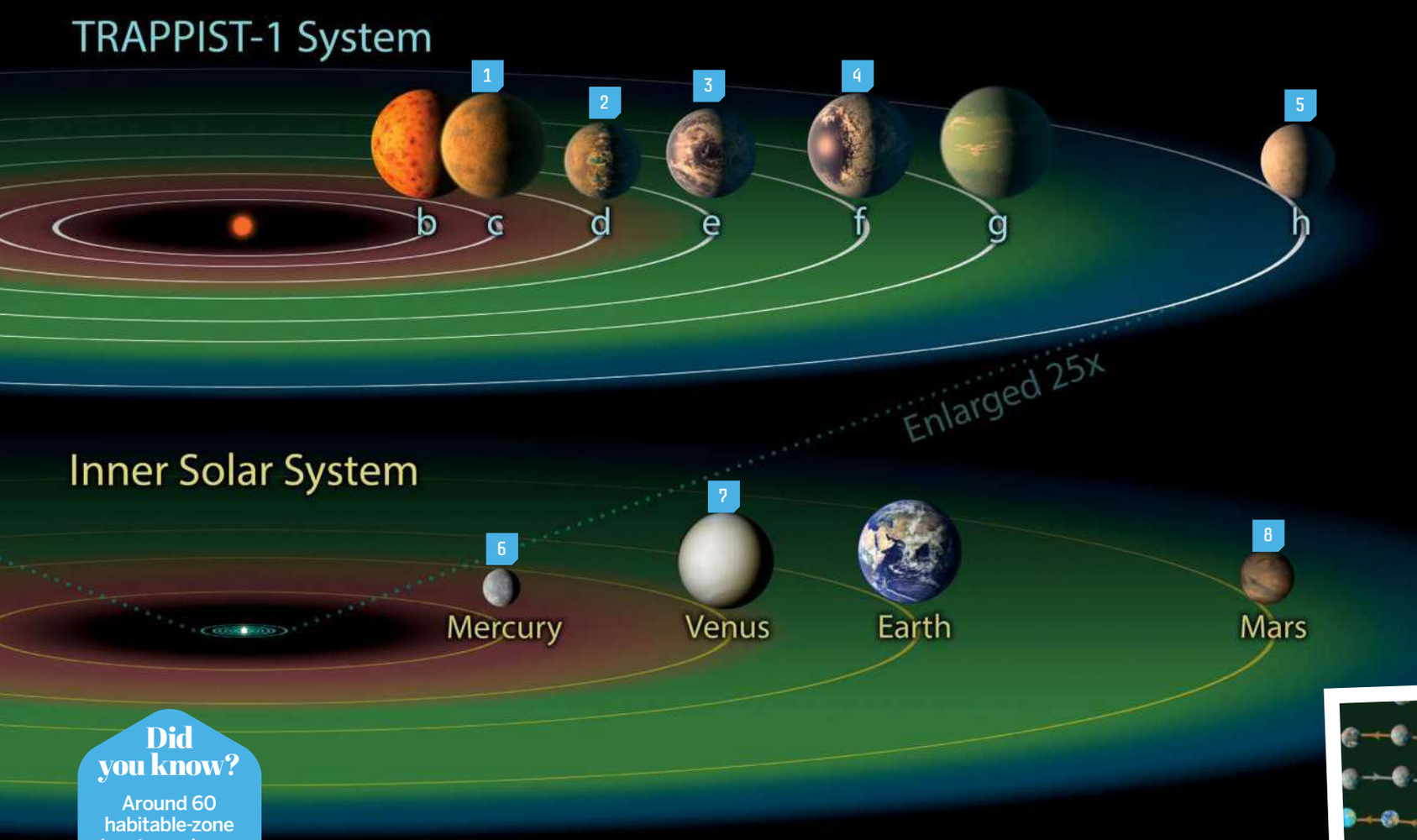
Computer-generated view from one of the 416 planets in the hypothetical 'Ultimate Engineered Solar System'

EXOPLANETS IN THE GOLDILOCKS ZONE

The discovery of new exoplanets orbiting distant stars has become almost commonplace. But it's always exciting when one is found within its parent star's Goldilocks zone. That happened in 2016 in the case of Proxima b, which orbits the Sun's nearest neighbour in space, red dwarf Proxima Centauri, just over four light years away. This star is so small and dim that its habitable zone is located at very close range, but Proxima B, which whizzes around the star once every 11 days, is safely inside it.

Another much-studied red dwarf is TRAPPIST-1. At around 40 light years away, it's farther than Proxima Centauri, but still a close neighbour in cosmic terms. TRAPPIST-1 is remarkable in having seven known rocky planets, three of them lying within the star's Goldilocks zone. It's possible that water is present on all seven planets, though only in a liquid state on the three inside the habitable zone. It would take the form of atmospheric water vapour on planets closer to the star or ice on the most distant of them. Astronomers are understandably keen to learn more about the TRAPPIST-1 system, and it's one of the planned targets for the James Webb Space Telescope.

Artist's impression of Proxima B, a planet in the habitable zone of Proxima Centauri



Did you know?

Around 60 habitable-zone planets are known to date

THE ULTIMATE ENGINEERED SOLAR SYSTEM

When a solar system forms, there's no reason planets should preferentially occur in the habitable zone, and the TRAPPIST-1 system is unusual in having as many as three planets there. But from a theoretical perspective, is there an upper limit to how many planets can be squeezed into the Goldilocks zone? That's a question that astrophysicist Sean Raymond addressed on his blog a few years ago. It turns out there is indeed a theoretical limit, beyond which the system becomes unstable because the planets are too close together. Raymond came up with what he calls the 'Ultimate Engineered Solar System', with a grand total of 412 planets in the habitable zone arranged around eight concentric orbits that rotate in alternately prograde and retrograde directions.

TWO HABITABLE SYSTEMS

TRAPPIST-1 and the Solar System have much in common, but are still quite different systems

1 TRAPPIST-1C
Too close to the star to be habitable, this planet may have a thick, swelteringly hot atmosphere like Venus.

2 TRAPPIST-1D
Around 40 per cent farther out than TRAPPIST-1c, this is probably still a little short of the habitable zone.

3 TRAPPIST-1E
This is the innermost planet in TRAPPIST-1's habitable zone and the one most likely to have Earthlike surface conditions.

4 TRAPPIST-1F
Right in the middle of the habitable zone, depending on its atmosphere this planet may have a lot of water.

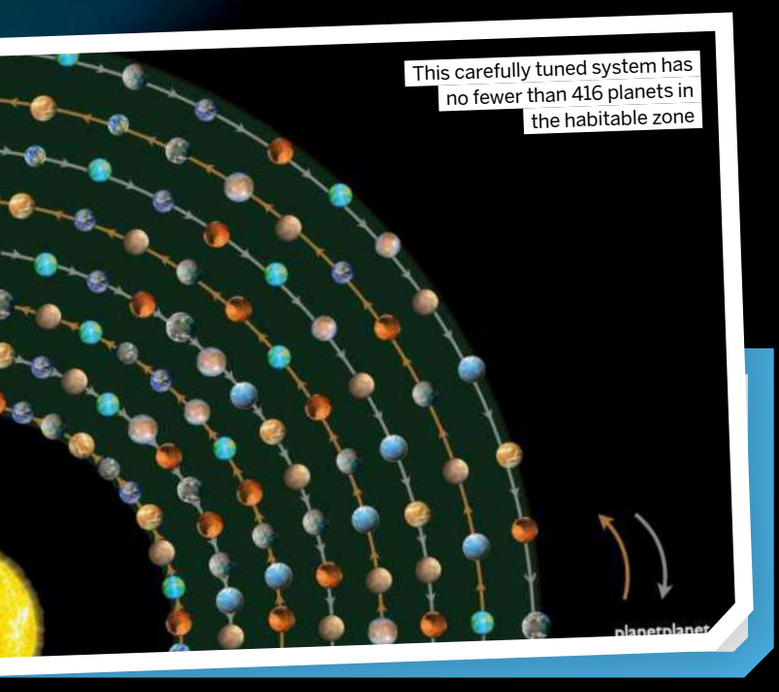
5 TRAPPIST-1H
The outermost of the known TRAPPIST-1 planets, this lies beyond the habitable zone and may resemble Saturn's icy moon Titan.

6 MERCURY
Estimates differ for the inner edge of the habitable zone, but they all lie well outside the orbit of Mercury.

7 VENUS
At 72 per cent of Earth's distance from the Sun, Venus is close to the Goldilocks zone's inner boundary.

8 MARS
Estimates for the outer edge also differ; depending which you use, Mars is just inside or outside the habitable zone.

"I tested the craziest systems using computer simulations"



Raymond writes about the interface of science and fiction at **planetplanet.net**

BUILDING THEORETICAL SOLAR SYSTEMS

We speak to Sean Raymond, originator of the 'Ultimate Engineered Solar System', about his work

How did you come to create such a strange arrangement of planets?
My day job is to understand how planetary systems form, what makes the Solar System different from exoplanet systems that we've discovered, and what types of orbital configurations are stable and which aren't. I wanted to figure out what type of orbital architecture would maximise the number of planets in the habitable zone – remaining stable but without having to worry about how the system would have formed. Luckily, I could use several recent papers by scientists as inspiration. I also tested the craziest systems using computer simulations to make sure everything held together.

Why do you call it the Ultimate 'Engineered' Solar System?
Originally I built two systems, each with about 30 planets in the habitable zone. Those systems could plausibly form in nature if just the right series of events took place – like rolling sixes on two dice ten times in a row. But I can't imagine how the Ultimate Engineered Solar System could form naturally. A system with equally spaced planets distributed along rings orbiting in opposite directions is just impossible as far as I know. If such a system exists, I would argue that it must have been built on purpose, presumably by the engineers of a super-advanced civilisation.

If such a system really existed, how could we detect it from Earth?
It would be pretty tricky to detect because the signals we measure to infer the presence of exoplanets – typically the radial velocity or transit signals – could end up being so confusing that they might be mistaken for noise in the case of the Ultimate Engineered Solar System.

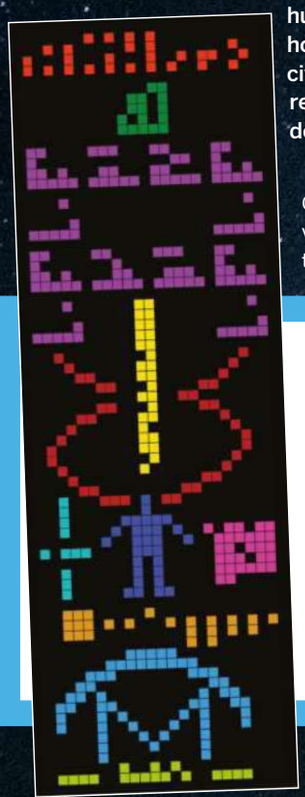
VOYAGER'S GOLDEN RECORD

What information did the Voyager spacecraft carry into space?

WORDS AILSA HARVEY

In 1977, two identical copies of a Golden Record were attached to the Voyager 1 and 2 spacecraft, serving as time capsules in space. The NASA-approved idea was to combine the Voyager program, which aimed to gather data from the Solar System and beyond, with a mission to deliver information about life on Earth to any intelligent life forms that may encounter the spacecraft. This is the introductory message – narrated by United Nations' secretary-general Kurt Waldheim – that's heard when the Voyager Golden Record is played: "I send greetings on behalf of the people of our planet. We step out of the Solar System into the universe seeking only peace and friendship, to teach if we are called upon, to be taught if we are fortunate. We know full well that our planet and all its inhabitants are but a small part of this immense universe that surrounds us. And it is with humanity and hope that we take this step." Waldheim mentions the record's potential to allow humanity to teach and be taught. The main purpose of the Golden Record is to share an insight of Earth and to provide evidence of humanity's existence in the hope that another intelligent civilisation in the universe will receive and be able to decipher the information.

Both were engraved



Colour has been added to this version of the Arecibo message to separate the sections clearly

THE FIRST MESSAGE

The first time humans deliberately sent a message to any potential alien civilisations was in 1974, in the form of a coded radio postcard. Called the Arecibo message, this attempted to explain humanity, just like the Voyager Golden Record. In an attempt to choose a language that would be easiest for extraterrestrials to decipher, binary code was used. Using this code, the receiver can reproduce the grid, with the ones and zeros of the binary code symbolising dark and light squares. When pieced together correctly, the shape of the human figure and the number of people on Earth at the time would be produced, as well as other information. The message was broadcast from the Arecibo Observatory in Puerto Rico and also included details about maths, DNA and the Solar System. The Arecibo Observatory was the largest radio telescope in the world at the time the message was sent. When transmitted, the radio message was directed at star cluster Messier 13.

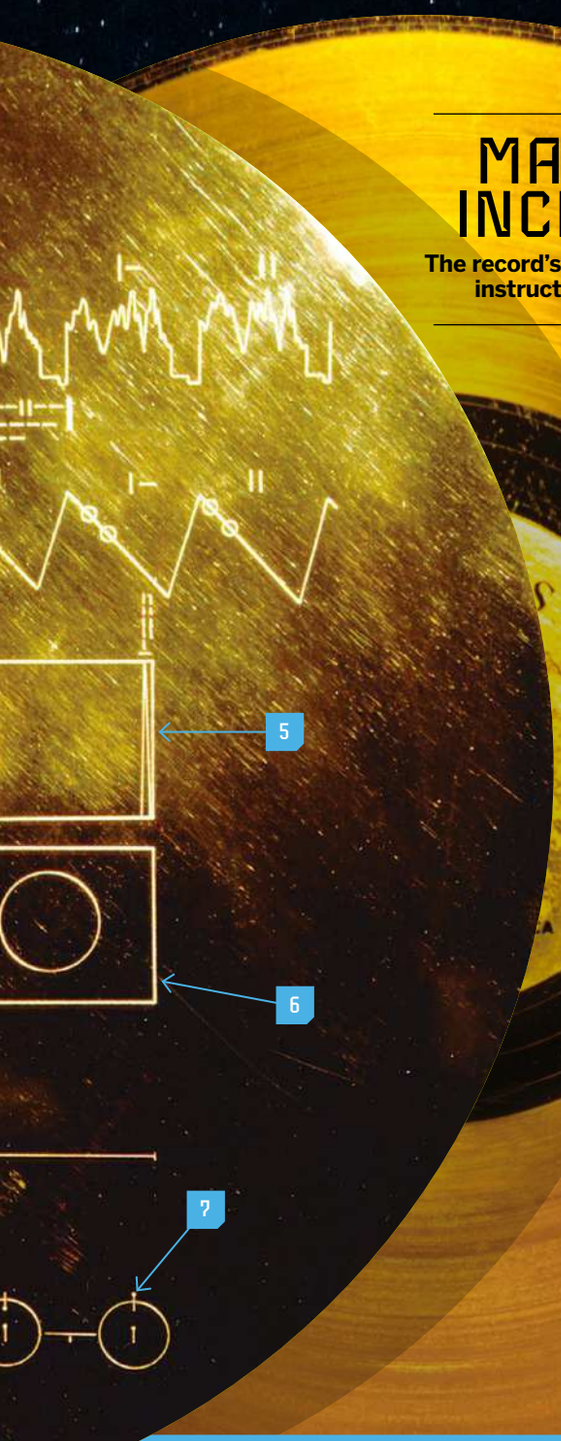
DID YOU KNOW? The Golden Records are 14.5 billion miles (Voyager 1) and 12 billion miles (Voyager 2) from the Sun

MANUAL INCLUDED

The record's engravings include instructions for its use

Did you know?

Each record is 30 centimetres of gold-plated copper disc



This image of people eating and drinking water is included on the record

Voyager project manager John Casani stands with the Golden Record and its golden cover

1 HOW TO PLAY
This is a diagram of the record to show how it should be played. The position of the stylus that comes with the record can be seen on the right of the circle, showing how to play it from the beginning.

2 SIDE VIEW
Below this side view of the record and stylus are binary numbers indicating how long it will take to play one side of the record. At 3.6 seconds per rotation, one side of the record will play for one hour.

3 PULSAR MAP
Our Solar System, at the centre, in relation to surrounding pulsars – quickly rotating neutron stars releasing radiation. Each line shows the relative distance of each pulsar.

4 PICTURE CONSTRUCTION
This diagram shows how the record produces pictures about Earth. The wavelength graph shows video signals in sequence to form a scan. The diagram illustrates each scan lasting three milliseconds.

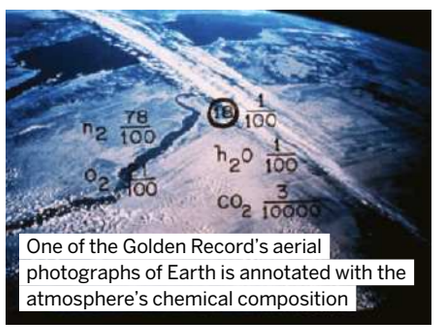
5 IMAGE GRID
This rectangular image frame shows that each one has 512 lines in it to produce a complete image.

6 SUCCESSFUL IMAGE
This circle shows the first image on the record in order to demonstrate a correctly rendered image.

7 HYDROGEN ATOM
These two circles are drawings of hydrogen atoms at their two lowest energy states. The line connecting the two shows the transition between the two states, serving as a timescale for the record's images.

EVIDENCE OF HUMANITY

As both Voyager spacecraft have entered interstellar space, the Golden Records have left the Solar System. One day, the information compiled here may be the last remaining evidence of humanity. This evidence includes 115 encoded photographs, 55 greetings in global languages, a 12-minute recording of sounds from Earth and 90 minutes of music. Some of the photographs include silhouettes of a man and a pregnant woman, people eating, the Taj Mahal, an aerial photograph of Earth, an image of Pluto, Olympic sprinters racing on a track and a page from Isaac Newton's book, *The System of the World*. The sounds that were chosen to represent Earth were those of humpback whales, brainwaves, storms, volcanoes and rocket launches. Among the chosen music artists were Mozart, Beethoven, Chuck Berry and electrical composer Laurie Spiegel.



One of the Golden Record's aerial photographs of Earth is annotated with the atmosphere's chemical composition

ENVIRONMENT

56 **How to survive almost anywhere**
Could you escape the wilderness with the bare minimum of tools?

62 **Camel anatomy: humps to hooves**
This mammal's unique features allow it to thrive in desolate lands

64 **How do fish breathe?**
Discover how aquatic animals use their gills to breathe underwater

66 **How Britain became an island**
The real Brexit started more than 8,000 years ago

68 **Why do moths eat clothes?**
How these tiny insects can wreak havoc on your wardrobe

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How to survive almost anywhere

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Camel anatomy: humps to hooves

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HOW TO SURVIVE ALMOST ANYWHERE

Could you escape the wilderness with the bare minimum of tools?

WORDS **ANDY EXTANCE**

It's the stuff of nightmares – suddenly you're on your own, somewhere wild, with nothing to help you survive. Could you make it out alive? Here we aim to give you some tips that might improve the chances of that. It's not an SAS-style survival bible, but a few things it would be useful to remember in a pinch.

In order to survive, we all need food, water, shelter, warmth and air. In most places on Earth, air is not a problem – so this won't cover the places that are. But you should start thinking of the other four points as quickly as possible if you ever find yourself in a survivalist situation.

Your first step if you are suddenly lost in the wilderness is usually to make a safe, comfortable shelter, start a fire and find a safe water source. Next, carefully assess your environment, looking for landmarks and working out which way is north, and make a plan. List everything that you have that you can use. This will help calm you down and boost your morale. If people know where you are, your best bet is to stay still until they find you. Similarly, if you can use smoke from your fire or a shiny surface to signal with, you could try to stay where you are and signal people to come to you.

Yet the plan will differ according to your environment and circumstances. People probably won't know where you are if you've washed ashore on a desert island. Extremes of heat and cold are especially challenging for finding enough to eat and drink. And in jungles, insects pose particular problems.

Whatever you do, don't panic and rush away unprepared. Take the time you need to make sure you're as well equipped as possible for your environment – that way you might get back safely.

DID YOU KNOW? The Inuit people say that in the barren north you need a large knife or a miracle to survive

ATTITUDE AS A SURVIVAL TOOL

Panic is never helpful, and in the wilderness it can be lethal. Instead, survival experts stress the need for a positive mental attitude. You can use the adrenaline flooding your system from your fear to your advantage. Keep your imagination on a leash. Don't let it run wild, thinking about the different catastrophes you may face. Try to fight pessimism, and believe that you will survive. That can be hard, so to keep panic under control, focus on small, productive tasks. Don't let yourself get lazy or complacent.

Make a list of key survival jobs, like making a shelter, and get them done well

ESSENTIAL KIT

If you plan to go into the wilderness, you should tailor your survival kit to your environment. But there are common themes. You should have some means of starting a fire for cooking and warmth. Opinions differ over the best option, but waterproof matches are effective. A good knife is essential, and for extra versatility you could make this a multi-tool, like a Swiss army knife. A whistle is important for signalling if you see people, and can scare away animals. A small torch is vital for providing light. A compass will help ensure that you're not travelling in circles.

Survival kits contain tools and gadgets that aren't found in a simple camping kit

FINDING LIFE-GIVING LIQUID

You need to drink several litres of water every day. Here's how to find it

Without water, you'll die in a few days. Your body is three-quarters water by weight. You lose water when sweating, peeing and pooping. This all has to be replaced. Even in comfortable climates your body needs about two litres a day to stay healthy. You need much more if you're travelling in hot places. Some recommend drinking a litre for every four miles covered, even if travelling at night, and twice that in the day. In cold places you also need more water because it's harder to move around and you need to generate more heat. You also need water to cook with, and to keep yourself clean.

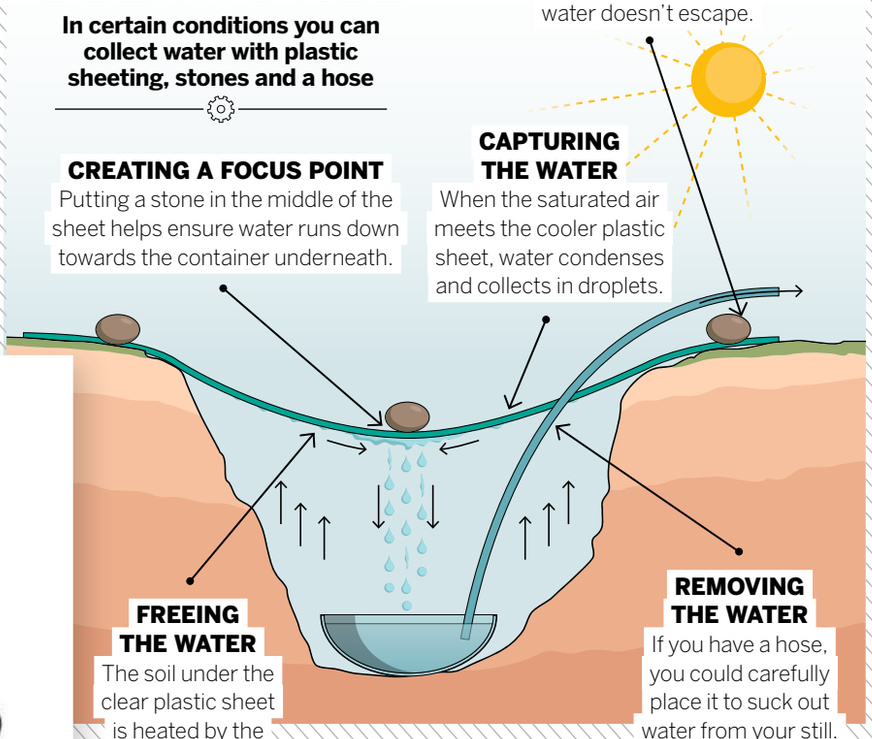
In fact, you need so much water, it's best to find reliable, clean sources like rivers and stay fairly close to them. That's especially difficult in deserts, where you need most water. You could try following a dried-up river bed in the hopes of finding a stream. Salty desert lakes can be found, in which case digging a shallow hole about 30 metres from the lake may yield potable water, as rain from the dunes travelling to the lake will gradually gather there. You can do something similar on beaches.

Finding water in rocky places can be hard, but you should look for springs and seepages. For example, in a clay landscape you might see an area with more plants where the rock is wetter. In jungles water is often plentiful, but contaminated. Water purification tablets are best here, but you can filter water through fabric. You can also find water pooled on big leaves or in tree trunks, but you should purify this too.

Given water is so important, it's good that there are many ways to find it. It's worth remembering a few ways, in case you're ever in desperate need of a drink.

MAKING A SOLAR STILL

In certain conditions you can collect water with plastic sheeting, stones and a hose



HOW TO FIND WATER

There are many ways to find water in the wilderness. Here are four top tips

DESALINATE SEAWATER

ENVIRONMENT: ISLAND

On an island you're surrounded by undrinkable water. You can boil it and capture the steam in a cloth. When it's soaking wet, you can wring out pure water.

FOLLOW THE ANIMALS

ENVIRONMENT: ANY

Everything from bees to bears to birds need water. Frogs in particular need it. If you see anything living, carefully follow them. They should lead you to water.

LOOK FOR PLANTS

ENVIRONMENT: DESERT

In a desert, look for where plants are growing, as they need water. Try to get up high and look downwards, as water is often found in low, shaded areas.

CUT THE ICE

ENVIRONMENT: ARCTIC

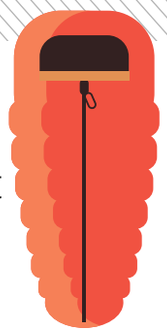
Eating snow doesn't actually get you much water, and melting ice needs lots of fuel. One good way to get water is cutting through a frozen lake or river surface.

WARNING!

BEWARE OF BAD WATER

Never drink from water that has dead animals or animal remains in it. The water probably has lots of minerals in it and has become toxic. You have the same problem with seawater – it's too salty to be healthy to drink. Sadly, birds and animals can sometimes drink water that's unsafe for people, so you can't ignore other clues if they're drinking water that looks bad.

FINDING A PLACE TO REST



A good place to relax is essential, but don't think you can sleep on open ground

Shelter can give you both a physical and mental boost. In cold environments, the only way you can rest is in a warm shelter, out of the wind. In a hot place a shelter could protect you from getting too hot. But even when things are fairly comfortable, a shelter can give an added boost of better sleep and feeling cosier. It will protect you from unpleasant changes in the weather, or interruptions from animals and biting insects.

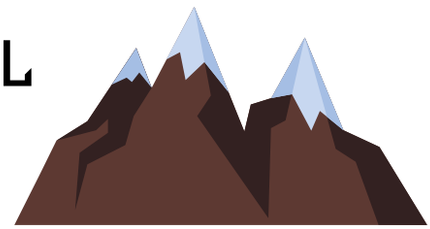
The kind of shelter you choose will depend on how much time you have available to set one up, and how long you intend to use it. For just one night there are various simple shelters you could make, or you could use a natural shelter. If you need to stay for longer, you should improve the shelter to make yourself more comfortable.

There are also unique considerations in different environments. If you are somewhere cold and snowy your shelter needs to be easy to build, because the cold saps your energy. It should also be windproof and warm, but let enough air out to avoid suffocating yourself.

Insects are a big problem in jungle environments, and can be hard to avoid if you haven't planned to be sleeping wild. At the very least you should try to shelter away from bodies of water, and with something between you and the ground. That could just be a piece of fabric, but if you can raise yourself higher off the ground, that would be even better.

FINDING NATURAL SHELTERS

Using landscape features can help you find shelter more easily



TREE BOUGH

ENVIRONMENT: JUNGLE OR FOREST

You can easily shelter under the bough of a tree, especially if it has fallen over naturally, or you can tie down a bough. Bough shelters are good camouflage.

CAVE

ENVIRONMENT: ANYWHERE ROCKY

A cave is an ideal shelter as it offers a roof, fairly constant temperature and is secure. However, you need to look out for other occupants, like snakes and bears.

NATURAL HOLLOW

ENVIRONMENT: TEMPERATE

A shallow depression in the ground will offer you some shelter from wind. You can also cover it with branches, grass, turf and bark to deflect rain and sunshine.

TREE PIT

ENVIRONMENT: ARCTIC

If you see a tree with thick lower branches surrounded in deep snow, you can dig a pit near the trunk to shelter in. Keep it small to retain heat.

DID YOU KNOW? Mauro Prosperi survived in the Sahara for nine days in 1994 by killing and eating bats and licking dew off rocks

BUILDING AN IGLOO

1 CUT BUILDING BLOCKS
Cut blocks from hard, dry snow about a metre wide, 40 centimetres high and eight centimetres deep.

2 SURROUND THE HOLE
Cut a circular groove around the hole you've just cut the blocks out of, deeper at one end than the other.

3 PILE UP THE BRICKS
You can now stack up the snow bricks in a continuous spiral, overlapping so that they lean inwards.

4 MAKE AN ENTRANCE
Cut a tunnel under the wall on one side. As well as being a way in, this traps cold air.

5 FILL THE HOLE
Put the last block on top of the igloo. It will be larger than the hole, so needs shaping.

6 FINISHED IGLOO
The finished igloo is warm – so warm it needs ventilation holes to avoid it melting.

AR zone SCAN HERE

TOP TIP!

AVOIDING TOILET TROUBLE

Hygiene is very important in the wilderness to avoid disease and insect infestation. Flies are annoying and can carry diseases. You should therefore designate a latrine space well away from your shelter, where the prevailing wind will blow the smell away. If possible, dig a hole to use as a latrine. You should poke around for biting insects with a stick before you sit over it. In rocky areas you may just need to cover your waste with stones.

Fire can be used to warm yourself, as well as cook meals and distil water

BRIGHTEN YOUR CHANCES WITH FIRE

A fire can keep you warm and dry, but also provides many more benefits

When it comes to survival, few things boost your mental attitude like fire. It's near the top of the list of wilderness tools because it's so versatile. You should build one as soon as you have shelter. It can help dry your clothes, cook meals, sterilise water, repel insects, make tools, cast light and do many other things. But it's not always easy to make a fire.

The best conditions for making a fire will be when it's fine and dry, with a light breeze. This kind of weather is ideal for practising how to do it. But often in the wilderness it will be rainy. Then you'll need to find shelter, for example a rock shelf. A large tree or tarpaulin might also work, but need to be far enough away as to not risk setting them on fire. You can also find a fat log, split it open and light a fire from underneath. You should be able to find dry wood for fuel in sheltered spots.

If you're building a fire on wet ground, mud or snow, you could make a log platform to start your fire on. If you're somewhere so windy it makes it hard to get a fire started, you can dig a pit to start it in.

Often you will be able to find wood to build a fire with, but that may not always be possible in arctic conditions. In these chilly circumstances, you may be able to burn peat, rotten vegetation that looks a bit like soil, seaweed or animal dung.

Thankfully, there are many ways that you can design a campfire. We only touch on a few here, but there are lots of different options depending on your circumstances. If you're serious about learning wilderness survival, it's important to carefully practise making them.

MAKE FIRE WITHOUT MATCHES

There are many ways to make fire without matches, but they take practice

WARNING!

BE CAREFUL WITH FIRE

Fire is essential if you're trying to survive in the wilderness, but it's also a great hazard. Burning yourself would make things much harder, and in the worst case you could die. You should always avoid windy areas where the fire can flare up out of control. Make sure there's nothing that can burn right near your fire. And when you move on, put out your fire.

FLINT AND STEEL

Scraping metal along flint – the hard, grey, easily breakable rock – makes sparks. If you catch the spark in a tinder ball, the tinder can catch on fire. The metal could be a knife, or part of a premade flint and steel.

MAGNIFYING LENS

It can take a long time, but on sunny days you can set fire to tinder with a magnifying lens. To do this you have to focus the light to a fine point. You could use eyeglasses, a magnifying glass or a binocular lens.

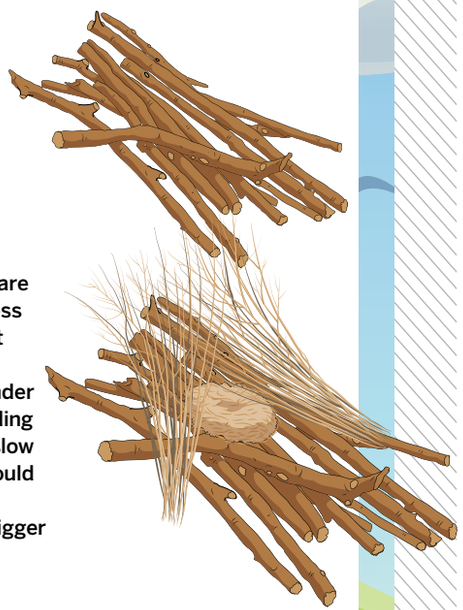
BOW AND DRILL

A bow is a curved piece of wood with a string attached. The drill is a hard wood spindle placed in a hole in a hard wood baseboard, with tinder in. Looping the string around the spindle and moving it back and forth ignites tinder through friction.

BUILDING A SIMPLE FIRE

KIT LIST

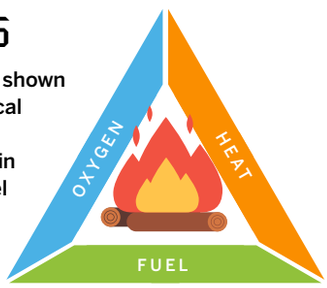
- Tinder: Easy-to-burn fine material such as shredded dry bark
- Kindling: matchstick-thick twigs
- Fuel: thumb-thick twigs
- Matches



Choose a fire site, and clear the ground to expose bare earth. Build a hearth by placing your thumb-thickness fuel twigs side by side. Kneel by the fire to protect it from the wind. Now pile the kindling on top of the hearth, propped up in a tent shape. Then put the tinder in the gap in the kindling tent. Strike a match, shielding the flame from the wind, and light the tinder. If it's slow to burn, blow on it gently to add more oxygen. It should now ignite your kindling, and from there the hearth twigs. This is a good quick fire, and can become a bigger one if you add more fuel. Other fire layouts may be better for purposes such as heating, however.

FIREMAKING'S THREE SIDES

Making fire requires three ingredients, sometimes shown in a triangle: oxygen, heat and fuel. Fire is a chemical process, primarily involving carbon in the fuel and oxygen from the air. The third element, heat, puts in energy to start breaking chemical bonds in the fuel and oxygen and making new ones, producing carbon dioxide. That process releases more heat, and now the fire can sustain itself.



FINDING YOUR WAY

If your tools get lost, nature can keep you on track

If your vehicle breaks down, or if you get off the track you were following, you need to find your way to your destination. Ideally you would have a map and compass and a device with GPS, but in the worst case scenario you might not even have that. How could you get to a safe place?

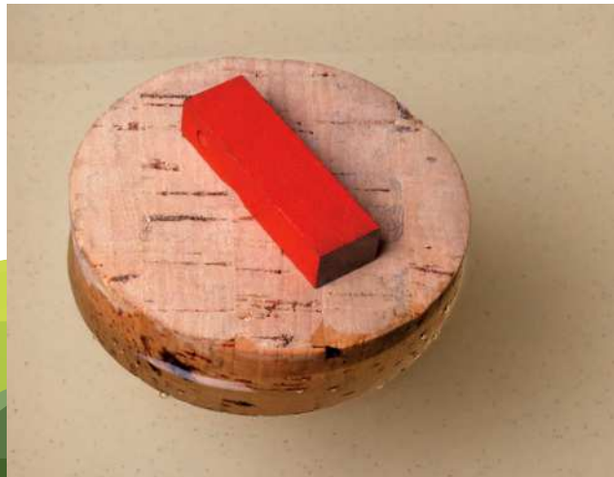
Throughout the history of humanity, we've used the Sun and stars to navigate by. If you know that the Sun rises in the east and sets in the west, and that the Sun is due south at its highest point, you can in principle follow a straight line out of the wilderness. Using the stars, you can look for the pole star in the Northern Hemisphere and the Southern Cross in the Southern Hemisphere. Landscape features can also act as guides. Streams, rivers and lakes can help stop you going back on yourself.

MAKE YOUR OWN COMPASS

KIT LIST

- Sewing needle
- Circle cut from cork
- A shallow bowl
- Pliers

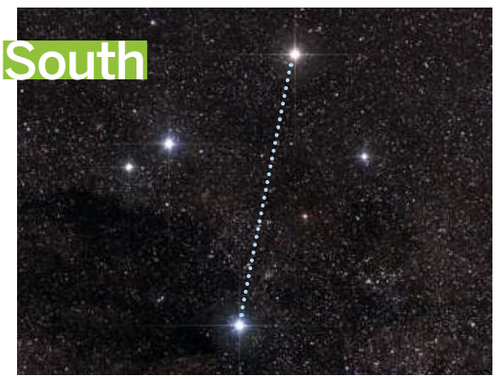
Rub the magnet from one end of the needle to the other a few times. Grip the needle with the pliers, and push it through the curved side of the cork. Push until you can see the same length of needle poking out of both ends. Fill the bowl with water, and float the cork on top. Put the bowl on a flat surface, and watch it align with magnetic fields. You can now take it outside and align yourself on a map.



DID YOU KNOW? Shivering means you are cold, but stopping can be worse – your body may have fallen below 32 degrees Celsius

STARS LIGHT THE WAY

Find the well-known Big Dipper asterism in Ursa Major. If you consider that this looks like a saucepan, follow a straight line from the vertical handleless side of the pan to the North Star.



The Southern Cross is relatively easy to see, with its four stars arranged like a crucifix. The longer line of the crucifix points towards the South Pole. Confusingly, there is another cross nearby, but that one has five stars.

TOP TIP!

STEERING BY THE SUN

In the daytime, you can find your way using the Sun. Find a stick that's about a metre long and fix it vertically into the ground. Place a stone on the tip of the stick's shadow. Wait at least ten minutes, and then place another stone at the tip of the stick's shadow. The line between the stones will point directly from east to west, the second stone at the east end, and the first stone at the west end.

KEEPING YOURSELF FED

Nutritious food can often be found alongside the bad

Hunger is another of the many discomforts the wilderness brings. It comes when our energy levels are low. In emergency situations, most humans will be able to survive for short periods by eating 500 to 800 calories per day. However, if you are in very hot or cold conditions, regulating your body temperature will use up more energy than normal.

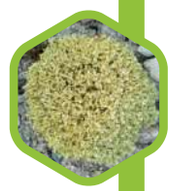
Humans have long hunted animals as a wild food source, but you may not have the skills to do this and there might not be any around. You can eat some insects, and there are many plants to eat. But not every plant is edible – if in doubt, don't eat it. If a mouthful of plant burns or irritates the mouth, it should not be swallowed, but this can't always be relied upon.

EATS AND DON'T EATS

What plants to look for and what to avoid in five different environments

EDIBLE

ICELAND MOSS
MOUNTAINS
This is a highly nutritious food source, but soak it and change the water twice before eating it.



MESQUITE TREE
DESERT
Beans of this tree are edible, and young, soft bean pods can be cooked and eaten like green beans.

MANGO TREE
JUNGLE
If you get lost in the jungle, you can hopefully find many familiar nutritious fruits like mangoes.

GREEN SEAWEED, OR 'SEA LETTUCE'
ISLAND
The sea is full of edible sea lettuce, used in sushi. It's high in protein and fibre.

WILD GARLIC
FOREST
With a distinctive smell, this vitamin-rich leafy plant with small white flowers can be abundant.

TOXIC

JIMSONWEED
DESERT
This has large white or violet trumpet-shaped flowers. All parts of the plant are poisonous to humans.

YELLOW OLEANDER
JUNGLE
These flowers contain milky sap, which must be avoided as it's highly poisonous.

CASTOR BEAN
JUNGLE AND ISLAND
While the castor bean is widely used in food, the outer covering of its bean is highly toxic.

FOXGLOVE
FOREST
Seeds contain the digitalis compound that makes your heart beat irregularly and makes you sick.

ARCTIC POPPIES
ARCTIC
With yellow petals and black hair, this plant is poisonous, but you can eat the leaves if you cook them.

CAMEL ANATOMY: HUMPS TO HOOVES

This mammal's unique features allow it to thrive in desolate lands

WORDS **AILSA HARVEY**

Like its own biological survival backpack, a camel's hump provides it with energy during prolonged periods of famine in barren environments. These distinctive protruding mounds store up to 36 kilograms of fat each. Depending on the species, a camel can have one, two or sometimes more of these lifesaving adaptations. When camels are unable to find food or water and begin to run out of energy from their last meal, they extract energy, vitamins, minerals and some moisture from their humps. This method has kept some camels alive for months without eating.

Instead of distributing their fat more evenly around their bodies, camels are the only animals that store it in great lumps. Without this even layer of insulation, heat can escape camels' bodies more easily, preventing their body temperature from rising too high.

These animals' bodies are tailored towards hot, dry habitats, mainly in sandy deserts around the equator. But some of their ancestors lived very different lives. Mummified remains of camel legs found in 2013 confirmed that these animals once roamed the Arctic tundra. This may have been how camels first developed their humps and became experts at living in extremes. 3 million years ago, camels survived in icy conditions with similar anatomy, which today helps them thrive in deserts. Energy reserves in their fatty humps enabled them to survive when skies were dark for months at a time and food was less accessible. This also gave them an advantage over other species when the Ice Age started, as they could outlive them on the same resources.

SPLIT LIP
The top lip is parted so that any moisture leaving the camel through its nostrils is directed into its mouth, reducing dehydration.

LONG EYELASHES
With three sets of eyelids and two rows of eyelashes, a camel's eyes are better protected in a sandstorm.

SLIT NOSTRILS
The thin opening of the nose prevents sand from entering the nostrils. Camels can also shut their nostrils when necessary.

BENEATH THE HUMPS

How have camels adapted to the desert?

THICK FUR
Air trapped in the thick fur insulates the camel from outside heat to keep the skin cooler. The hairs also trap moving air to prevent heat being carried to the skin by the wind.

A group of camels is called a caravan

DID YOU KNOW? A camel can drink a quarter of its own weight in water at a time

FAT-FILLED HUMPS
Humps store fatty tissue. When food is scarce, this fat is metabolised to release nutrients.

A camel's fur keeps it cool in the day and warm at night

EXTENSIVE INTESTINE
Camels need all the water they can get in desert lands. Their long small intestines have a large surface area to maximise water reabsorption into the body.

WIDE FEET
A camel's weight is distributed evenly across this relatively wide surface area. This makes the animal more stable.

STOMACH CONTENTS
Sometimes camels regurgitate their food to re-chew. This can help when digesting tough foods and sometimes allows for extraction of more nutrients.

Did you know?
Baby camels can walk within 30 minutes of being born

WHAT'S ON A DESERT MENU?

When food is limited, animals can't afford to be fussy eaters. Camels are herbivores and rely on desert shrubs, grasses and twigs. Their mouths are tough and able to withstand thorns, but their lips remain flexible enough to grab and break off food.

Their stomachs have three or four chambers, which can prolong digestion to thoroughly break down tougher meals. The increased surface area of the stomach means moisture in the plants they eat can be better absorbed before leaving the body. Eating plumps up camels' humps, and after a long time without food they will shrink.

Camels can eat cactuses by grinding sharp thorns on their mouth palate

CAMEL BEHAVIOUR

Camels are social animals, often traversing deserts in male-led groups. When greeting each other, they're known to blow in each other's faces. Different noises are made when camels 'talk' to each other. These include moans and hums. When a female camel gives birth, she usually separates herself from the herd. The mother looks after the calf alone before rejoining the herd two weeks later. For the next 10 to 12 months she will produce milk for her young.

Female camels need to find enough food to produce milk for their young

HOW DO FISH BREATHE?

Whale sharks have five large gill slits on each side of their heads

Discover how aquatic animals use their gills to breathe underwater

WORDS **ANDY EXTANCE**

Goldfish don't look much like gorillas, but the way these creatures breathe has something in common. They both need the gas we call oxygen to survive. Oxygen helps release the energy that powers our bodies from the sugary chemical glucose in a process called respiration. Respiration releases another gas, carbon dioxide, which gorillas, humans and fish breathe out. Gorillas can suck oxygen from the air through their mouths down into their lungs to breathe easily. Goldfish have it harder.

Did you know?

Tiny ectoparasites can live inside fish gills

To breathe, fish have to pull out the molecules of oxygen dissolved in water using their gills. The amount of oxygen in the air is a lot higher than the amount of oxygen in water, though. That means that fish have a much more difficult time breathing than gorillas and humans do. Fish take water into their mouths just like we take in air, opening and closing their lips. This water then filters through the gills, organs that have lots of feathery filaments made of protein molecules.

The filaments look like tiny bristles on a brush. They have thousands of tiny blood vessels to help oxygen get into the bloodstream – even more blood vessels than in human lungs. The larger number of blood vessels in fish gives a much larger surface for oxygen to pass across. That helps them pull the dissolved oxygen from the water around them and release carbon dioxide back into it.

The difference in design between lungs and gills is the main reason why people – and gorillas – can't breathe underwater. Gills are much better at pulling oxygen from water than lungs. Fish extract over four-fifths of the oxygen available in water. Fish also use less energy to live than mammals like humans and gorillas, so need less oxygen. They do need at least some oxygen though. That means that water with low oxygen levels is just as deadly for fish as low oxygen in the air can be for us. Anoxic and hypoxic zones, sometimes called dead zones, are areas of the ocean where oxygen is so scarce that fish cannot survive.

If breathing underwater is such hard work, why don't fish just breathe air like we do? Gills need water to maintain their structure and prevent their thin tissues from collapsing. Just like humans drown underwater, fish can drown in air. If their gills are exposed to the open air for too long, they can collapse, causing the fish to suffocate. They are especially suited for life underwater, just as we are for life on land.

The axolotl is an aquatic amphibian with gills sticking out of its head

FISH THAT CAN BREATHE AIR

Labyrinth fish are named after their lung-like labyrinth organs, which have many maze-like compartments known as lamellae. Those labyrinth organs help some fish species, including bettas, gouramis and paradise fish, to breathe air just like humans do. They also have gills so they can breathe oxygen dissolved in water.

For millions of years, these fish and their ancestors have lived in very low-oxygen waters. Evolution has favoured any fish that are born with advantages that help them make the most of the oxygen they can find.

If the water labyrinth fishes live in runs out of oxygen, they can dash up to the surface and use their labyrinth organs for a gulp of air. They can even survive for hours outside of the water. Many labyrinth fish also build bubble nests. Males can blow bubbles to create elaborate nests of air at the surface of the water.

Betta splendens, or Siamese fighting fish, have labyrinth organs to breathe air

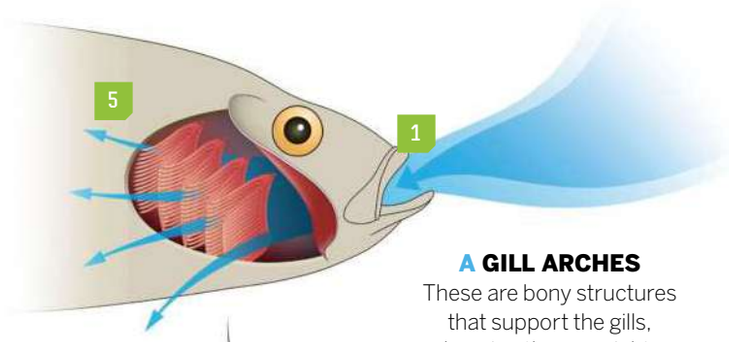
DID YOU KNOW? Crabs, aquatic snails and lobsters all use gills to breathe

EXPLORING GILLS

Fish gills are intricate organs, especially suited for efficient gas exchange

Some aquatic animals, like dolphins and whales, get their air using lungs like we do

5 OPERCULUM
Water leaves the gills through the operculum.

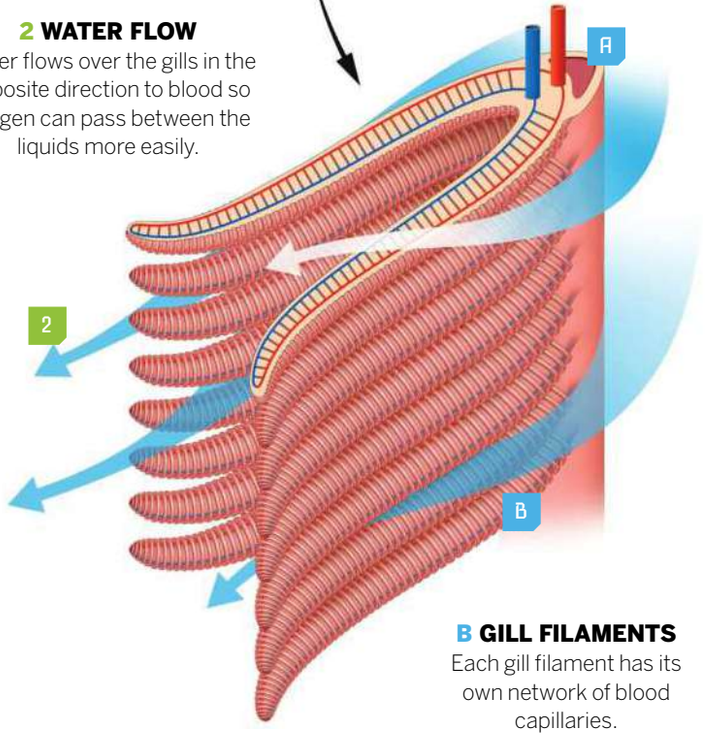


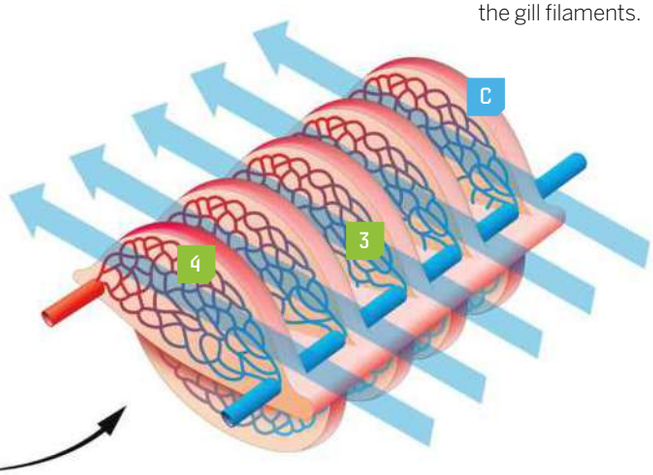
1 BUCCAL CAVITY
Water enters through the fish's mouth, also known as the buccal cavity.

C CAPILLARY NETWORK
Thousands of blood vessels make up each capillary network in the gill filaments.

A GILL ARCHES
These are bony structures that support the gills, keeping them upright.

2 WATER FLOW
Water flows over the gills in the opposite direction to blood so oxygen can pass between the liquids more easily.





4 OXYGENATED BLOOD
Once the blood has gained oxygen, it delivers it to the rest of the body.

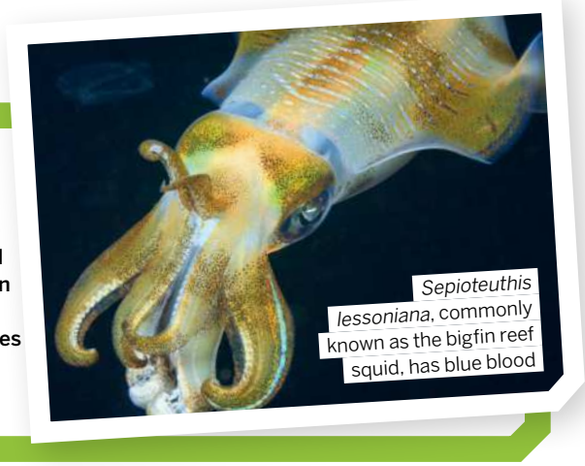
3 DEOXYGENATED BLOOD
Blood without oxygen from the body enters the gill filaments to pick up oxygen.

B GILL FILAMENTS
Each gill filament has its own network of blood capillaries.

"Fish extract over four-fifths of the oxygen available in water"

BLUE-BLOODED CREATURES

If you cut most animals, blood comes out red. By contrast, many underwater creatures, like crabs and lobsters, octopuses and squid, bleed blue. Our blood is red because of a chemical called haemoglobin in our blood cells. Haemoglobin includes an atom of iron, which clings on to oxygen molecules. Blood cells containing haemoglobin then carry oxygen around our bodies, working like a bright-red delivery van inside our blood vessels. Blue-blooded creatures have a chemical called hemocyanin instead of haemoglobin. It works in a very similar way, using copper instead of iron. The copper atoms turn their blood blue.



Sepioteuthis lessoniana, commonly known as the bigfin reef squid, has blue blood

A depiction of Doggerland's ancient residents

HOW BRITAIN BECAME AN ISLAND

The real Brexit started more than 8,000 years ago

Did you know? There have been five major ice ages in Earth's history

WORDS **SCOTT DUTFIELD**

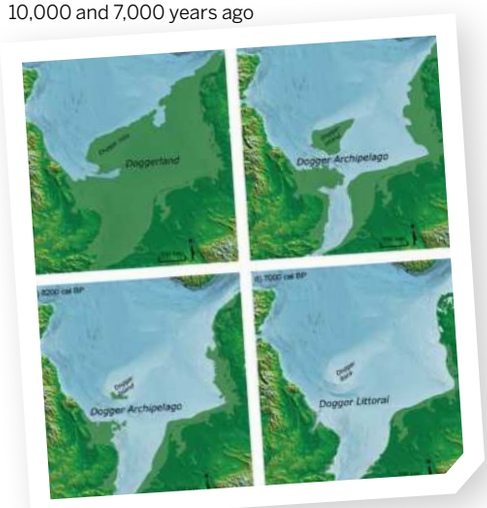
Around 18,000 years ago, during the Pleistocene Epoch, the majority of modern-day Britain was covered in ice. This period of glaciation persisted for thousands of years, lasting until around 12,000 years ago after a warming climate brought the icy expanse to an end. In the wake of the ice age, today's North Sea and the English Channel were filled with grassy marshland, wooded valleys and swamps. This area of land, known as Doggerland, once connected Britain with mainland Europe and spanned over 18,000 square miles.

The beginning of the end for Britain's connection to Continental Europe began around 8,200 years ago when a massive tsunami struck Doggerland. Off the coast of Norway, an enormous underwater landslide known as the Storegga Slide shifted more than 720 cubic miles of material through the water – this is 300 times the annual sediment output from all the world's rivers.

The Storegga Slide was likely triggered by seismic activity following a period of deglaciation across Norway. The rapid movement and displacement of water caused by the slide generated enough energy to create the tsunami. The enormous wave would have reached heights of up to 20 metres. The tsunami swallowed up Doggerland, crashed into the northeast of Britain and travelled 25 miles inland, making it a newly formed island. It's largely accepted that the Storegga Slide-triggered tsunami is the predominant cause of the sinking of Doggerland and the separation of Britain and mainland Europe. However, some studies have found that something else may have severed the final link between the two.

By analysing the seabed and its sediments, researchers at the University of Bradford have discovered that the tsunami might not have been solely responsible for sinking Doggerland. Following the flooding, several smaller islands formed a 'Dogger archipelago', which remained for almost a thousand years. Between 8,400 and 8,200 years ago, the global average sea level rose – possibly in two phases – between one and four metres. This rise in sea level was linked to climate change, and by around 7,000 years ago the Dogger archipelago would likely have completely disappeared under the sea.

How Doggerland changed between 10,000 and 7,000 years ago



LIVING ON DOGGERLAND

When the Storegga tsunami hit the northwest of Europe, it not only drowned landmass, it also decimated ancient communities living on Doggerland. Human skeletal remains have been collected from fishing and dredging along the North Sea bed. Radiocarbon dating of the remains revealed that the majority belong to Mesolithic humans – living between 20,000 and 8,000 years ago – who resided on Doggerland. Archaeological evidence suggests that those who lived on Doggerland were hunter-gatherers.

At the time of the tsunami there would have been around 5,000 early humans scattered around Britain, who travelled from Continental Europe following the migration of mammoths and reindeer. Rising sea levels would have forced Doggerlanders to flee the lower lands – now sitting under the English Channel – and escape to higher landmasses in modern-day England and the Netherlands.

DID YOU KNOW? During the last ice age, glaciers covered around eight per cent of Earth's surface

DIVORCING EUROPE

Britain's separation from the European mainland throughout the ages

1 450,000 YEARS AGO
Britain underwent one of the harshest ice ages in its history, known as the Anglian Stage. Shallow valleys that spanned between modern-day France and England flooded as the ice melted, beginning the formation of the English Channel.

2 400,000 YEARS AGO
As global temperatures rose, evidence of an ice age melted away. This caused sea levels to rise, but Britain remained connected to Europe by a narrow land bridge. It was during this time that Neanderthals ventured into Britain.

3 125,000 YEARS AGO
Sea levels continued to rise, eroding the land bridge and eventually engulfing it. Britain became an island, but it was much smaller than it is today – most of Lincolnshire was underwater.

4 60,000 YEARS AGO
During this time, global ice had largely retreated to the poles, lowering sea levels, and once again Britain and Europe were married together with grass-covered plains. Over the thousands of years that followed, *Homo sapiens* made the trip across those plains into Britain.

5 20,000 YEARS AGO
The last ice age hit Britain, and the majority of its human population disappeared over the next 10,000 years.

6 8,000 YEARS AGO
Phases of sudden warm and moist global conditions brought about the end of the ice age. Britain and Europe split for the final time due to an enormous tsunami and the ensuing rise in sea levels.

An adult clothes moth (*Tineola bisselliella*)

Eggs embedded in carpet

WHY DO MOTHS EAT CLOTHES?

How these tiny insects can wreak havoc on your wardrobe

WORDS **SCOTT DUTFIELD**

If you've ever pulled out your favourite jumper from the closest and found some unexplained holes in it, then you may have a moth problem. Crawling around in the dark corners of your wardrobe might be one of two species of clothes moth: the webbing clothes moth (*Tineola bisselliella*) or the case-bearing clothes moth (*Tinea pellionella*). These tiny insects have a wingspan of under 20 millimetres, hairy heads and large eyes. The easiest way to tell these moths apart is by looking at the colour of their wings. Webbing clothes moths have a golden sheen to their wings, whereas case-bearing clothes moths are a dull grey-brown colour.

Clothes moths live across the world and can be found in warm, dark and damp areas around your home. These moths have gained a bad reputation for devouring expensive cashmere and woollen jumpers, but it's not the moths that do the damage – it's their offspring. As adults, clothes moths are unable to eat anything. However, their larvae have an insatiable appetite. Clothes moth larvae have evolved a specific diet of a material found in natural fibres such as wool, called keratin. It's the same material that makes up your fingernails and your hair. The clothes moth caterpillars use the keratin to spin silk, which they use to build temporary homes and finally metamorphic cocoons to transform into adult moths.

Did you know?

There are some 160,000 species of moths on Earth

The larvae tuck into keratin-rich fibres, the clothes in our wardrobes, carpets and pretty much any piece of fabric with natural fibres in it that they can find. Their taste for keratin-rich fibres not only poses a threat to fashion and furniture, but also puts the preservation of many historical artefacts at risk. The National Trust identified clothes moths and silverfish (*Lepisma saccharina*) as the most prevalent pests to threaten their collections. The trust has gone as far as trialling the release of microscopic parasitic wasps, along with moth pheromones, to interrupt the moth's life cycle and eradicate the pests.

CARPET CUISINE

Clothes moths aren't the only insects with a taste for carpet fibres. Some of the most prolific carpet grazers come from a group of beetles. Appropriately known as carpet beetles, there are three species that wreak havoc in the UK: the varied carpet beetle (*Anthrenus verbasci*), the black carpet beetle (*Attagenus pellio*) and the brown carpet beetle (*Attagenus smirnovi*).

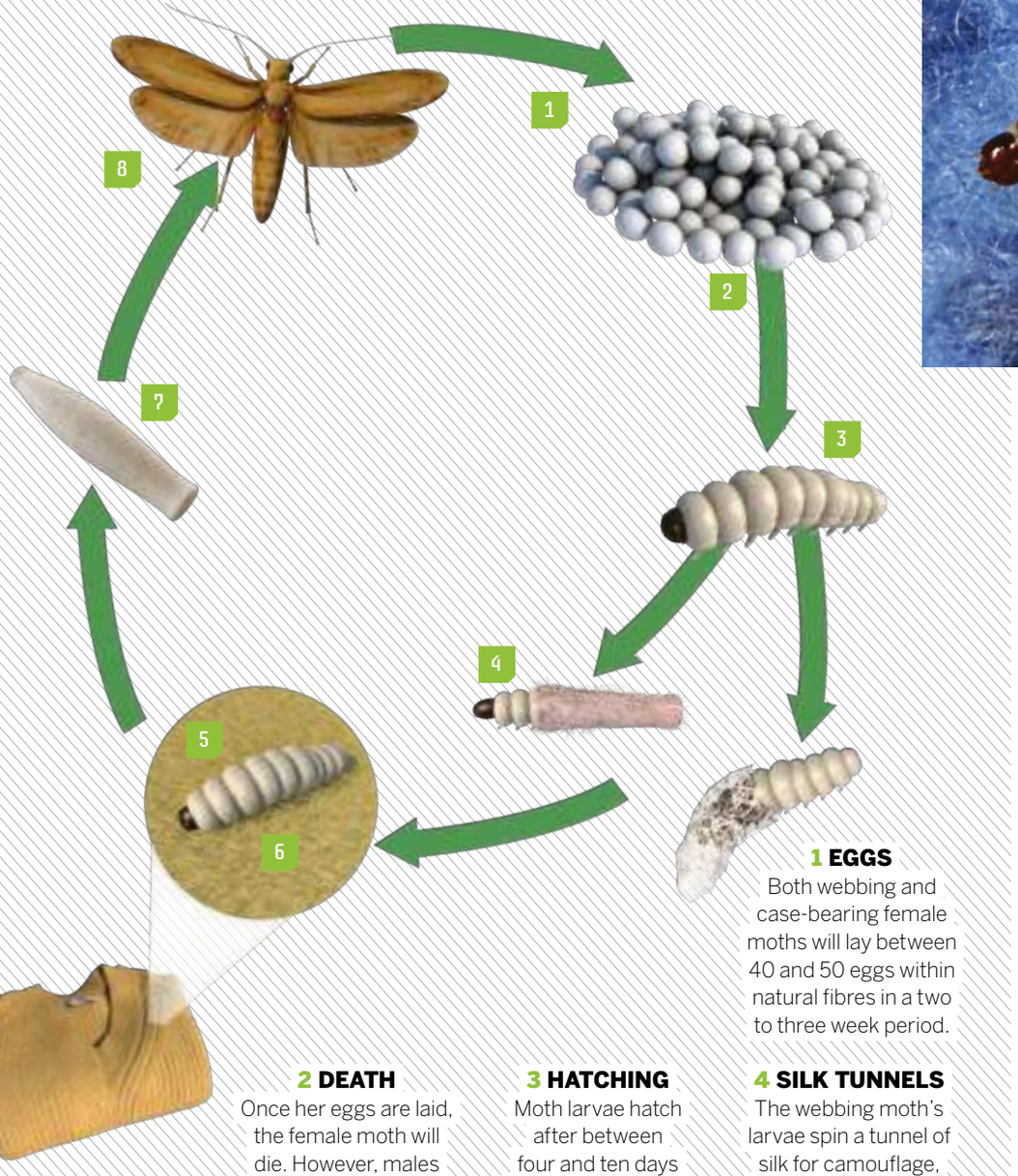
Females lay around 100 white eggs within the carpet, in flooring cracks and on clothing. On a warm summer's day, the eggs will hatch after around 15 days of development. Like clothes moths, it's the larvae of the insects that do all the damage. They too have a taste for wool, although they devour synthetic fibres such as polyester and rayon if they are heavily soiled with food stains. Carpet beetles are rapid breeders, with up to four generations scurrying around at any one time.

The adult varied carpet beetle (*Anthrenus verbasci*), a major pest in the UK

DID YOU KNOW? Evidence on Roman archaeological material suggests they brought clothes moths to Europe

THE LIFE CYCLE OF A CLOTHES MOTH

From egg to adult, how these moths grow up eating your clothes



A larva of the case-bearing clothes moth

1 EGGS
Both webbing and case-bearing female moths will lay between 40 and 50 eggs within natural fibres in a two to three week period.

2 DEATH
Once her eggs are laid, the female moth will die. However, males outlive females, continuing to mate for up to a year.

3 HATCHING
Moth larvae hatch after between four and ten days during the summer months.

4 SILK TUNNELS
The webbing moth's larvae spin a tunnel of silk for camouflage, which they emerge from at night to feed on fibres.

5 CARRY CASE
The larvae of the case-bearing moth do as their name suggests,carrying their silk home around with them while they eat.

6 DEVELOPMENT
Larvae have at least five development stages that cause them to moult over a period of time, which can last between 35 days and two-and-a-half years.

7 METAMORPHOSIS
Once the larval stage is complete, they will create a silken cocoon, and while inside will metamorphosis in adult moths. This process takes between 10 and 50 days.

8 ADULTHOOD
As soon as they emerge from their cocoons, adults will run – not fly – around on fabrics or carpet in a frenzy to find a mate. Females will lay new eggs in one to two days

5 WAYS TO TACKLE MOTHS

1 DEEP CLEAN
Moths enjoy dark undisturbed areas in your wardrobe and drawers. Deep cleaning these areas, along with all the clothes within them, can kill the larvae.

2 FREEZE
Putting clothes that might be home to moth larvae into plastic bags and then the freezer for up to 48 hours should kill larvae.

3 GARMENT BAGS
Store any valuable woollen knits in zip-lock or vacuum-sealed bags to prevent moths from laying their eggs on them.

4 MOTH REPELLENTS
There are a range of products, such as anti-moth paper strips and draw liners, available that work to actively repel moths from laying eggs on your clothes.

5 INVEST IN CEDARWOOD
Clothes moths do not like cedarwood. Simply placing sticks of cedarwood in your wardrobe or investing in cedarwood clothes hangers could help to deter moths.

HISTORY

72 **12 Unbelievable inventions**
These famous products were designed for one thing, but found success doing something completely different

80 **Communism versus fascism**
What are these two opposing ideologies?

84 **Welcome to the cradle of civilisation**
How the ancient society of Pakistan's Indus Valley shaped the modern world

86 **What was the battle of the Alamo?**
The outcome of this two-week battle between Mexican and Texian forces proved pivotal in the Texas Revolution

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Welcome to the cradle of civilisation

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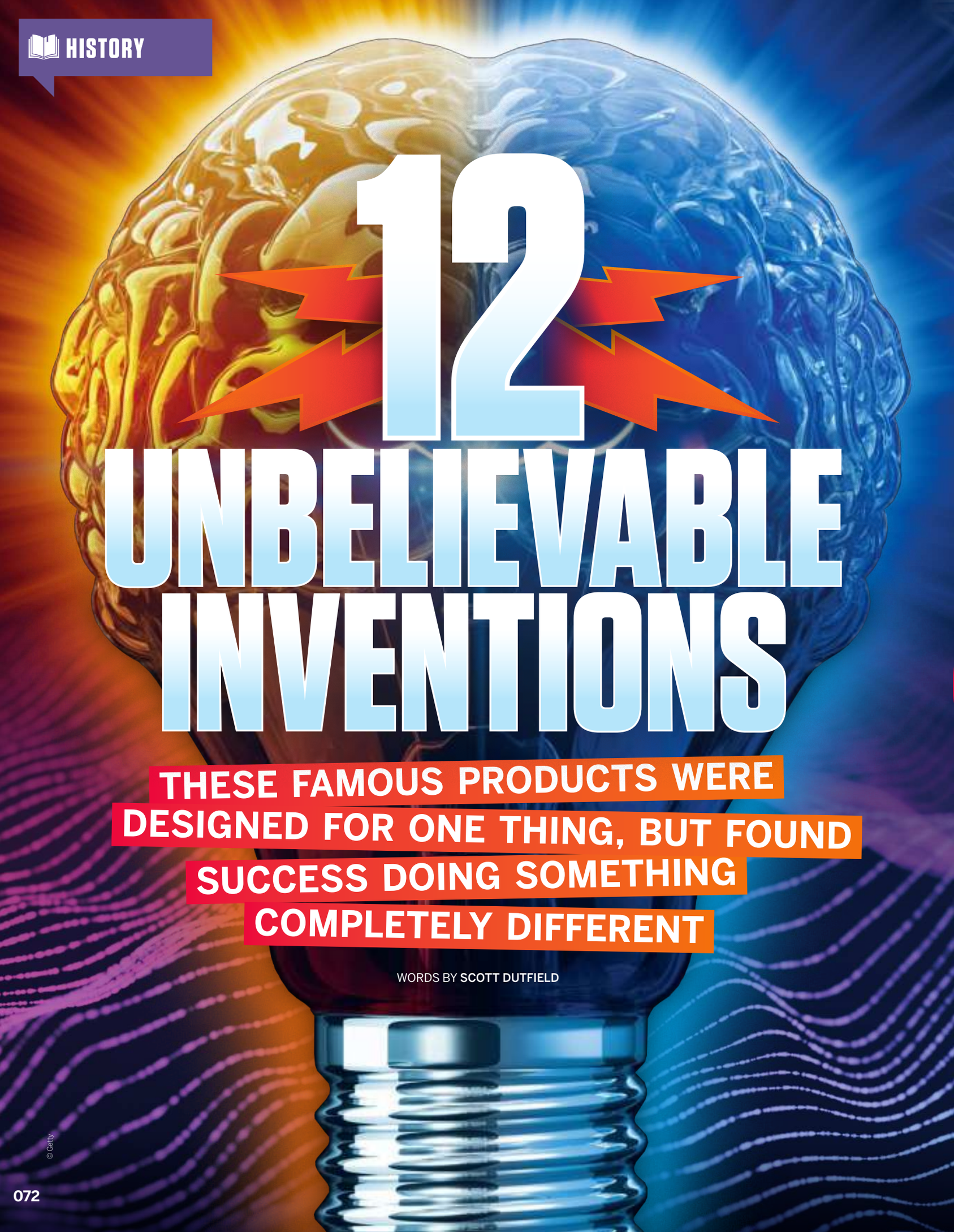
What was the battle of the Alamo?

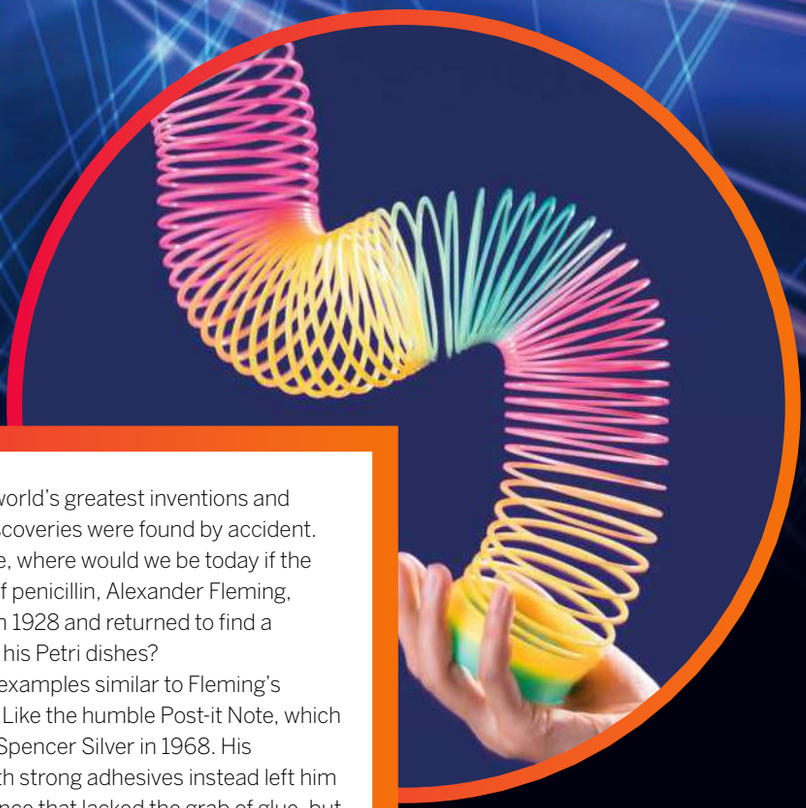


12 UNBELIEVABLE INVENTIONS

THESE FAMOUS PRODUCTS WERE DESIGNED FOR ONE THING, BUT FOUND SUCCESS DOING SOMETHING COMPLETELY DIFFERENT

WORDS BY **SCOTT DUTFIELD**

DID YOU KNOW? The Guinness Book of World Records once listed Teflon as the slipperiest substance on Earth

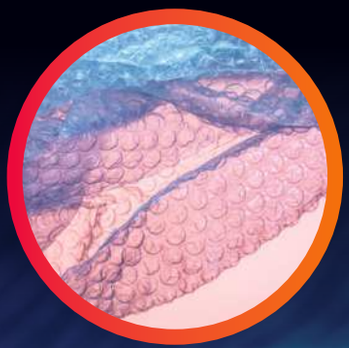


Some of the world's greatest inventions and scientific discoveries were found by accident. For example, where would we be today if the discoverer of penicillin, Alexander Fleming, hadn't gone on holiday in 1928 and returned to find a fungus killing bacteria in his Petri dishes?

History is awash with examples similar to Fleming's unexpected discovery. Like the humble Post-it Note, which was created by Dr Spencer Silver in 1968. His experiments with strong adhesives instead left him with a substance that lacked the grab of glue, but could stick to surfaces and peel away easily.

Teflon is another product where a discovery was made by chance. In 1938, Dr Roy J. Plunkett was experimenting with different refrigerant gases, including tetrafluoroethylene (TFE). In one refrigerator the gas appeared to be missing, but upon further inspection, Plunkett found that the TFE had polymerised into a white powder called polytetrafluoroethylene (PTFE). This new substance was super slippery and had a high melting point, making it perfect for creating non-stick kitchenware.

Some discoveries were made after an invention had already hit the supermarket shelves. They're proof that just because something is created for one purpose doesn't mean it can't be used more successfully for another. Here are some of the world's most famous products with the most surprising origin stories.



THE SCIENCE BEHIND SLINKIES

The story goes that the Slinky's inventor, Richard T. James, first discovered the recreational use of the metal spring while working as a naval battleship engineer during the early 1940s. James was developing coils of metal called tension springs that were used on ocean vessels to hold onboard equipment in place. While working at his desk, one of these springs fell and began to 'walk'. Seeing the potential to market the tension spring as a toy, he took the idea home to his wife Betty, who named it the Slinky after looking through a dictionary.

In 1945 James perfected the design of the Slinky, which consisted of approximately 24 metres of wire coiled into a helical five-centimetre-tall spring. The following year, James filed a patent for a machine that could make a Slinky in just ten seconds. The Slinky went on to become the must-have toy of the mid to late 20th century, and in 2000 was inducted into the National Toy Hall of Fame, having sold more than 250 million units.

Slinkies come in lots of bright colours and designs

© Getty

© Getty

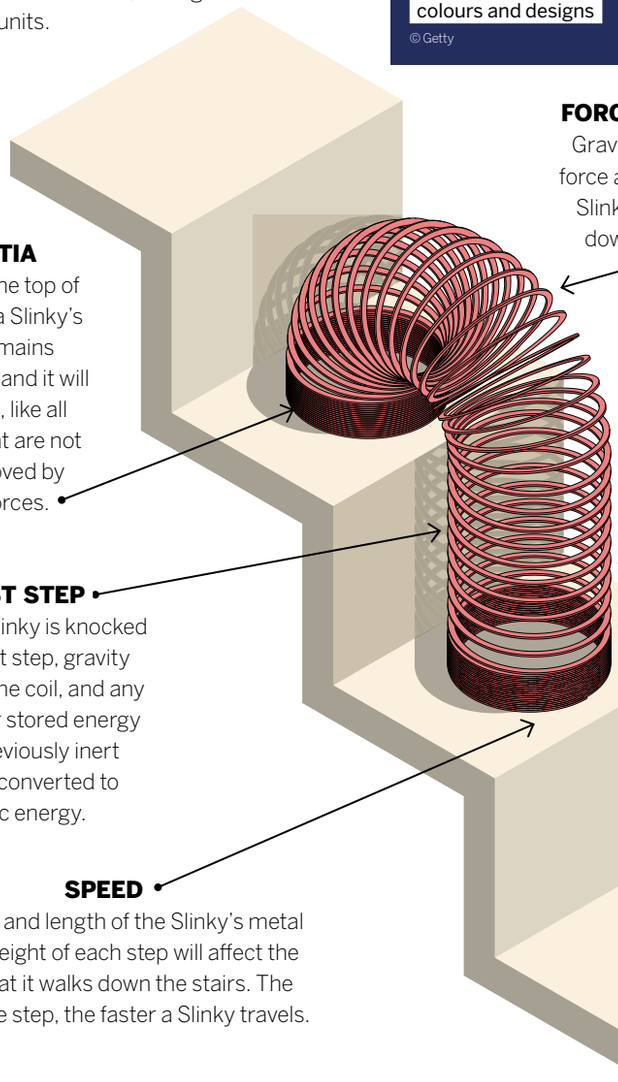
MR CELLOPHANE

In the kitchen drawers of countless homes around the world, you'll probably find a roll of cling film, or Cellophane. This clear roll of plastic has been around since 1908, when Swiss chemist Jacques E. Brandenberger created a waterproof film intended for coating fabrics.

The film appeared after Brandenberger applied a liquid viscose rayon on materials and then peeled away the transparent layer. He saw potential for this new material in the packaging industry, and so patented his creation 'Cellophane', named after the raw material cellulose – the main substance of plant cell walls – and diaphane, an obsolete word meaning transparent.

SLINKY PHYSICS

How this famous spring walks down stairs



FORCES AT PLAY
Gravity is the main force acting upon the Slinky as it 'walks' down the stairs.

INERTIA
Sitting at the top of the stairs, a Slinky's state remains unchanged and it will not move, like all objects that are not being moved by other forces.

FIRST STEP
When the Slinky is knocked off the first step, gravity acts upon the coil, and any potential or stored energy in the previously inert Slinky is converted to kinetic energy.

SPEED
The mass and length of the Slinky's metal and the height of each step will affect the speed that it walks down the stairs. The steeper the step, the faster a Slinky travels.

TRANSFERENCE OF ENERGY
With each step the Slinky takes, energy is transferred along the length of the coil in a compression wave, similar to how sound waves travel.

© Ed Crooks

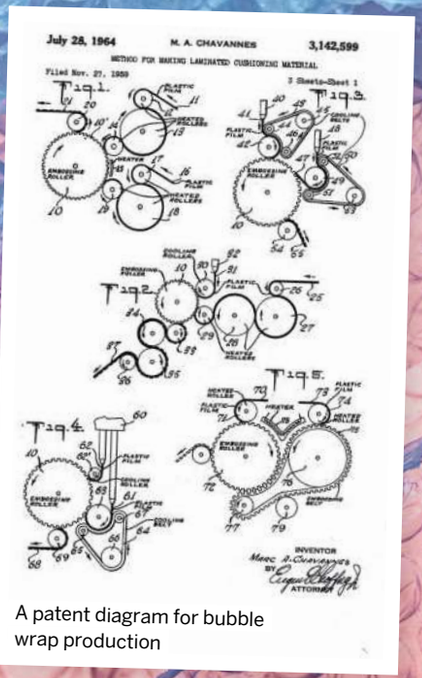
DID YOU KNOW? In 2017, Hasbro trademarked the distinctive scent of Play-Doh

BUBBLE WRAP WALLPAPER

Bubble wrap is synonymous with sending packages or protecting your precious belongings. However, in the 1950s you were more likely to see it covering your walls than crammed into a box. The idea for bubble wrap came from the minds of Alfred Fielding and Marc Chavannes, who made an attempt to create a textured wallpaper in 1957. Having heated two sheets of plastic shower curtain together, the pair created a single sheet with several trapped air bubbles.

The coinventors obtained several patents for their creation, making attempts to market it as wallpaper and even as greenhouse insulation, but bubble wrap never took off as an interior decoration. The two coinventors founded Sealed Air Corporation in 1960, and the following year diversified their product as a packing material, which soon found success.

The soft bubbles keep what's wrapped inside safely cushioned


July 28, 1964 M. A. CHAVANNES 3,142,599
METHOD FOR MAKING LAMINATED CUSHIONING MATERIAL
Filed Nov. 27, 1959 2 Sheets-Sheet 1
INVENTOR
ATTORNEY

A patent diagram for bubble wrap production

© USPTO

© Getty

BUILDING BUBBLE WRAP

How plastic is transformed from pellets into poppable packaging


© Alamy

1 PLASTIC PELLETS
Bubble wrap starts its life as pellets of polyethylene resin. These are vacuumed through pipes to an extruder.


© Alamy

2 HEATING UP
The resin pellets are heated at temperatures over 260 degrees Celsius. The pellets melt as a result, forming a film.


© Getty

3 SUCKING UP
One layer of film is placed on a cylinder coated with small holes. Using a vacuum, the film is then sucked into the holes.


© Getty

4 TRAPPING AIR
A second layer of plastic film is then rolled on top of the vacuumed film to create a seal, trapping the air bubbles within.


© Getty

5 CUT TO SIZE
The now-joined films are rolled into large sheets of bubble wrap and cut into smaller pieces.

PLAY-DOH CLEANER

Around 318 million kilograms of Play-Doh has been squashed between the fingers of children around the world. But did you know that Play-Doh was initially invented as a cleaning tool, rather than a toy? The malleable material was created by Cincinnati-based cleaning company Kutol in the early 1900s. Its intended use was to remove the soot from people's wallpaper, which accumulated from coal-burning fireplaces. However, with the introduction of wipeable vinyl wallpaper and the increase in household oil, gas and electric heating, the need for Kutol's putty quickly declined. Its rebranding was down to the sister-in-law of Kutol's cofounder, who proposed that the putty's non-toxic ingredients meant it would be perfect for playtime.


Play-Doh is completely safe in the hands of children

© Getty

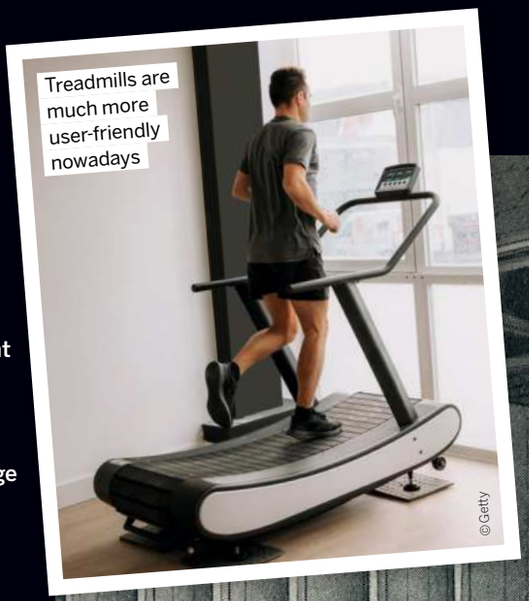
PENAL TREADMILLS

After gorging on a takeaway, hopping onto the treadmill in the morning may feel like atonement for a crime. But that's exactly what treadmills were created for during the early 1800s. Examples of treadmill-like contraptions have been around since the Romans constructed large cranes powered by people walking on a wheel. But the modern-day article was conceived of in the 1800s.

As a cruel method of enforced exercise, the evolution of the treadmill began in 1818, when civil engineer William Cubitt created the treadwheel. It was intended not to improve the fitness of the public, but to punish prisoners.

Installed into Brixton Prison, London, the treadwheel turned under the feet of up to 24 prisoners, each stepping on the wooden slats of an elongated wheel. It included dividers so that prisoners could not socialise, and it could be ten hours before prison guards would let them off the torturous device. Although the invention of the treadwheel was initially designed as a punishment, over time prison officials put them to practical use to pump water or grind corn.

It wasn't until 1902 that the penal treadmills such as Cubitt's creation were abolished in Britain, but treadmill technology continued to evolve for personal fitness.



Treadmills are much more user-friendly nowadays

© Getty

ENFORCED FITNESS

How these immoral machines kept prisoners walking for hours

HOLD ON TIGHT
Handrails were placed along the wheel to prevent prisoners falling off.

SEPARATION
To prevent the prisoners from interacting with one another, penal treadmills were equipped with dividers, similar to bathroom stalls.

LONG DAYS
Prisoners spent at least six hours a day on treadwheels as part of their hard labour sentence. This would have equated to climbing around 4,260 metres vertically.

RESISTANCE
In some prisons, guards could alter the resistance of the wheel by opening large panels called vanes. Closing the vanes made it harder to turn the treadmill.

© Alamy

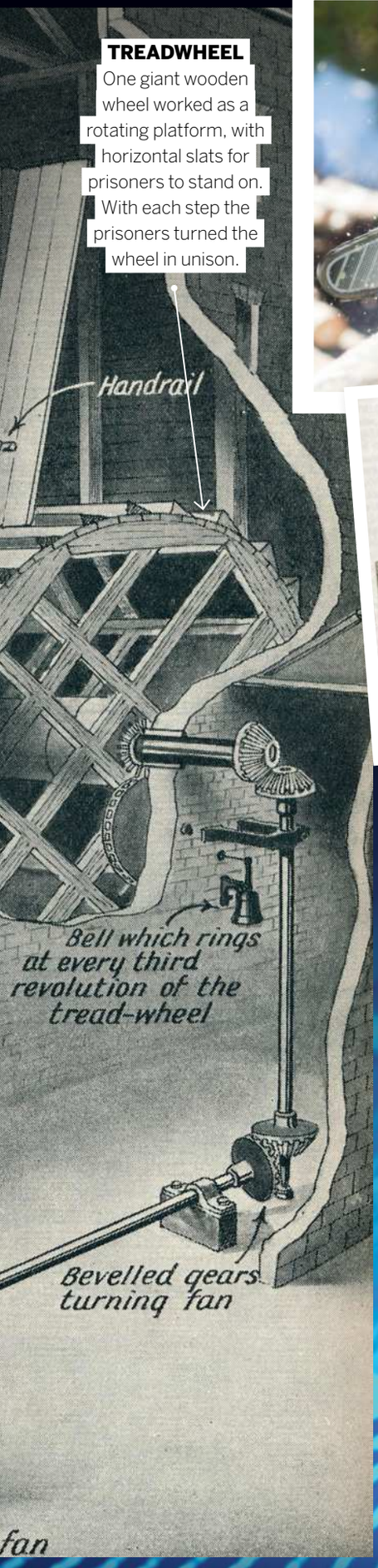
BATTLE-BORN BOTTLE OPENER

Although the exact origin of the corkscrew remains unclear, it's believed that its design was developed from 'gun worms'. These military screws were commonly used in the 1600s to extract trapped musket balls from the barrels of guns. The corkscrew-like devices would twist into the lead of the ball, allowing the soldier to swiftly remove it.

It's believed that this military kit inspired the first generation of simple wine 'cork worms'. It wasn't until 1795 that a British clergyman, Reverend Samuel Henshall, filed the first patent for the corkscrew.

Source: Wiki/Unknown author

DID YOU KNOW? The first American penal treadmills were introduced to New York in 1822



TREADWHEEL
One giant wooden wheel worked as a rotating platform, with horizontal slats for prisoners to stand on. With each step the prisoners turned the wheel in unison.

© Getty

CHAINSAW OPERATIONS

Chainsaws are pretty effective at ripping into wood, but back in the late-18th century, it was bone rather than bark that they tore through. The evolution of the chainsaw began between 1783 and 1785, when two Scottish doctors called John Aitken and James Jeffray invented the chain hand saw. This serrated link chain was used to successfully cut away diseased bone and remove afflicted joints such as the knee or elbow. Over time Aitken and Jeffray's simplistic design was developed, and in 1830 Bernhard Heine created a drive more reminiscent of the modern-day version.

Known as the chain osteotome, Heine's device also used a serrated chain, but included a handle mechanism. It worked in a similar way to hand-powered rotary whisks, but instead of beating eggs, it could precisely cut through bone quickly. The osteotome meant that surgeons could perform surgeries without the restrictions of bone splinters or damaging the surrounding tissue.

The chainsaw's move from bone to bark came about when American inventor Samuel J. Bens patented the first 'endless chainsaw' in 1905. The stationary device consisted of a large, looped, 'endless' secreted chain which was "furnished with driving power, such as a steam-engine, gas-engine or motor of any kind".

Chainsaws weren't made with trees in mind

Source: Wiki/Hans555

WD-40

It's now a household product around the world, but WD-40 was initially created to assist the aerospace industry as a rust-prevention solution. It took WD-40's inventors, a company called Rocket Chemical Company, 40 attempts to perfect this water-displacement formula, hence the name. It was used to coat the skin of the Atlas missile, the US Air Force's first operational intercontinental ballistic missile (ICBM), to prevent it from corroding.

Seeing its potential as a household product and a useful tool for car mechanics, WD-40 hit supermarket shelves in 1958. Although initially perfected in 1953, the same formula for WD-40 is still in use today. Now the iconic blue-and-yellow cans can be found in their millions around the world, and in 2020 the revenue of WD-40 Company reached $408.5 million (£295 million).

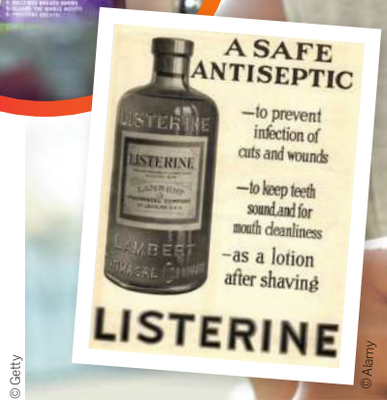
WD-40 can hold back rust from rockets

© Getty

THE MANY USES OF LISTERINE

© Getty

Other than providing a cool, refreshing oral feeling, Listerine was created to offer an antiseptic solution in the operating theatre. Named after its inventor Sir Joseph Lister, the founder of the practice of antiseptic medicine, the alcohol-based formula was created in 1879 to remove disease-causing organisms and was a good disinfectant for surgical instruments. It was also used as a solution for treating wounds, curing dandruff and cleaning floors. Eventually dentists got hold of Listerine and used it to improve oral hygiene in dental patients. In the 1920s, a marketing campaign that branded Listerine the treatment for the relatively unheard of 'halitosis', or bad breath, made it the go-to mouthwash for the public.



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ROGAINE REGROWTH


© Alamy

In the 1960s, pharmaceutical company Upjohn, now part of Pfizer, created a new kind of medicine to treat hypertension (high blood pressure). This medication was called minoxidil and proved popular with clinicians, so much so that the US Food and Drug Administration (FDA) approved it as an emergency protocol for severely ill patients in 1971. It was later discovered that 60 to 80 per cent of hypertensive patients developed an unusual side effect, called hypertrichosis. This condition results in excessive hair growth anywhere on the human body. Researchers quickly found that minoxidil stimulates follicular growth. As a result, in 1988 the new 'Rogaine 2% Minoxidil Solution for Men' was introduced as a prescription-only solution to hereditary hair loss.

STIMULATING REGROWTH

How your hair grows and how Minoxidil gives follicles a boost


© Alamy

ANAGEN
In the first stage of hair growth, specialised cells divide into cells that make up the shaft of a hair, receiving nutrients from a capillary loop at the base of a follicle.

CATAGEN
At this stage the hair follicle shrinks, detaches from the capillary loop and moves towards the skin's surface.

TELOGEN
For around three months a hair will sit in this resting phase before moving on to the exogen phase.

EXOGEN
In the shedding phase, the hair is discarded from your body. Between 50 and 100 hairs are shed from your body each day.

ROGAINE
To tackle hair loss, typically known as androgenic alopecia, minoxidil works to prolong the anagen phase and promotes regrowth via the follicle capillary loop.

DID YOU KNOW? Coca-Cola once marketed itself as a potential replacement for morning coffee

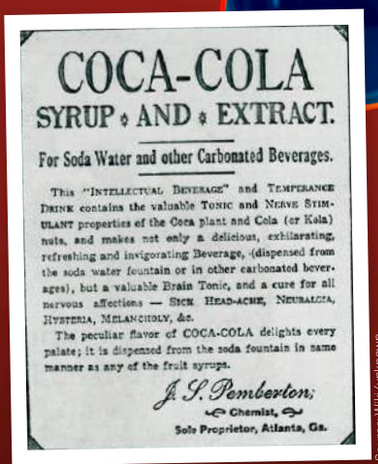
CRAVING COCA-COLA

Arguably one of the most beloved carbonated drinks on the market, today Coca-Cola sells more than 1.9 billion servings, enjoyed in 200 countries every single day. The original recipe of the drink, however, would not be so well received these days.

Coca-Cola began as a way for its pharmacist creator John Pemberton to tackle his dependence on morphine. He'd been injured in the Battle of Columbus in the late-19th century, and like many veterans, Pemberton became dependent on pain relief medicines such as morphine. Seeking an alternative to this addictive opiate, Pemberton came across a tonic called French Wine Coca, made by Parisian chemist Angelo Mariani. The tonic promised health rejuvenation from its Bordeaux wine and coca-leaf extract mixture.

The energy-boosting effects of the drink were likely due to the presence of cocaine, the active ingredient in coca-leaf extract. Until 1914 cocaine was not illegal, and was often used in tonics and pills to treat a myriad of medical conditions causing nausea, asthma and constipation.

Pemberton created his version of the wine to sell commercially, but a local prohibition law in 1887 saw quick removal of the tonic because of its alcoholic content. Quickly reformulating the popular beverage, Pemberton substituted the drink's alcohol content, replacing it with sugar syrup and adding caffeine-rich kola-nut extract. The coca-leaf extract remained in the beverage, and the drink became completely cocaine-free in 1929, when scientists removed the psychoactive components of the leaf extract.


COCA-COLA
SYRUP * AND * EXTRACT.
For Soda Water and other Carbonated Beverages.
This "Intellectual Beverage" and Temperance Drink contains the valuable Tonic and Nerve Stimulant properties of the Coca plant and Cola (or Kola) nuts, and makes not only a delicious, exhilarating, refreshing and invigorating Beverage, (dispensed from the soda water fountain or in other carbonated beverages), but a valuable Brain Tonic, and a cure for all nervous affections — Sick Head-ache, Neuralgia, Hysteria, Melancholy, &c.
The peculiar flavor of COCA-COLA delights every palate; it is dispensed from the soda fountain in same manner as any of the fruit syrups.
J. S. Pemberton,
Chemist,
Sole Proprietor, Atlanta, Ga.

Coca-Cola's original recipe was a cocaine cocktail

© Getty

Source: Wiki/unknown

SECRET INGREDIENTS AND COLOUR: 0.17307%
A secretive blend of natural flavours are added. Besides coca extract, it's speculated that this includes lots of natural oils, including those from nutmeg, lemon, coriander, cinnamon and orange. Coca-Cola Original uses a colourant called caramel 150d. This additive uses a combination of sulphite and ammonia reactants to create its brownish colour.

ENERGY BOOST: 0.00972%
In a standard can of Coca-Cola there is around 34 milligrams of caffeine. However, in the diet version this amount rises to 46 milligrams.

ACIDITY: 0.1719%
To add tartness, Coca-Cola includes a small amount of phosphoric acid. However, this acid wreaks havoc on the enamel of your teeth.

INSIDE COCA-COLA

Take a look at what's inside that classic red bottle

SWEET TASTE: 10.8%
In around half a litre of Coca-Cola there is approximately 65 grams of sugar.

FIZZ: ~89%
Around 90 per cent of Coca-Cola is water, which has been pumped with purified carbon dioxide to give it its fizz.

THE MOOD BOOSTER

Similar to the creation of Coca-Cola, the refreshing taste of 7UP was concocted as a life-changing elixir. In 1929, Charles Leiper Grigg created a new lemon-flavoured drink called 'Bib-Label Lithiated Lemon-Lime soda'. The formula for the drink contained lithium, which continues to be used as a mood enhancer to treat conditions such as depression and bipolar disorder. 7UP hit supermarket shelves only two weeks after the American stock market crash in 1929 and the start of the Great Depression. Lithium was removed from 7UP's recipe in 1948 following a government ban in America of its use in soft drinks.

Old branding for 7UP marketing it for the whole family

© Alamy

COMMUNISM VS FASCISM

What are these two opposing ideologies?

WORDS **AILSA HARVEY**

FASCISM THROUGH THE YEARS

1919

The 'fascist era' began at the end of World War I, lasting until 1945, the end of World War II.

9 Nov 1921

Benito Mussolini founded the National Fascist Party.

1922

Benito Mussolini of Italy became the first fascist leader.

1933

The Nazis rose to power and introduced 'Volksgemeinschaft', the idea of creating one race in Germany.

1939

From 1939 to 1945, fascists in Italy and Germany tried to gain power over the rest of Europe.

1947

After WWII, most were against anything resembling Nazism. Fascist movements became small scale.

1970

Many anti-fascist and anti-racist groups were created in this decade, like the Anti-Nazi League.

DID YOU KNOW? Benito Mussolini was a fan of socialist Karl Marx before turning to fascism

Fascism and communism are two very different ideologies, but both claim to strive for 'perfection'. These images of perfection, however, are polar opposites. During the 20th century, fascism and communism went head to head. Both groups wanted to rebuild societies consistent with their utopian vision, acquiring as many followers as possible along the way. At their most extreme these dreams were inhumane, or faced problems in practicality when followed in the long term. Fascism is much less prevalent in modern society, but communist ideologies still survive in a handful of countries.

Communism is based on the idea that all people should have equal opportunities and wealth, while fascist governments have discriminated against different races and religions in order to favour a specific one. The totalitarian form of a fascist government places all authority in the hands of one dictator. These leaders have included Francisco Franco of Spain, who allowed no religion other than Catholicism, and Adolf Hitler, who focused on creating a one-race Germany with total disregard for all others. These are just two examples of the multiple fascist leaders who held warped perceptions of perfection.

Some communist governments of the past have proven to be equally as controlling. Typically, countries under communist rule are required to comply with its core ideologies. Communism aims to create equality among all people, but this has proven problematic to achieve. In contrast to capitalism, which allows individuals and organisations to earn a profit for their work, any properties or other earned resources in a communist state are owned by the government, to be redistributed more evenly. When personal reward is taken away, many believe that the incentive to achieve and to do so ethically is reduced. Meanwhile, extreme measures have been used in past communist governments to force compliance. This includes Joseph Stalin's rule of the Soviet Union between 1924 and 1953. During this time, it's estimated that he was responsible for the deaths of between 20 million and 60 million people.

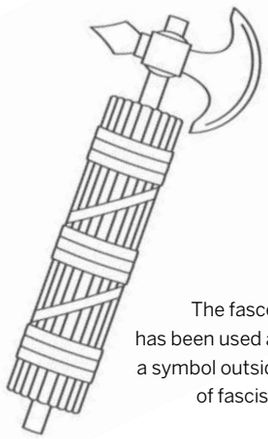
Did you know?
The fasces was also a symbol in ancient Rome

WHAT IS FASCISM?

The word 'fascism' comes from the Italian 'fascio', meaning a bundle or group, and is considered a term for a militant brotherhood. The word 'fasces' means an axe tightly bound with sticks, an image that became a symbol of the fascist movement.

Fascism uses propaganda techniques to promote anti-liberalism – rejecting individual rights, civil liberties, free enterprise and democracy – anti-socialism – rejecting economic principles based on socialist frameworks – exclusion of certain groups and nationalism that seeks to expand the nation's influence and power.

Fascism promotes the concept of innate inequality and inescapable social hierarchies between groups. Underlying this hierarchy is the idea that a person's rank in society is determined by aspects of identity that are beyond their control, such as ethnicity or gender.



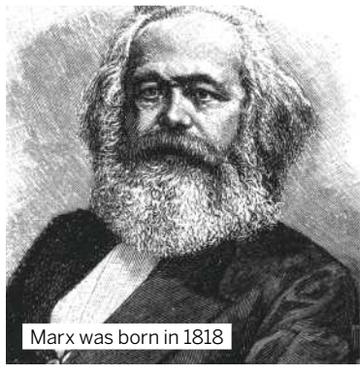
The fasces has been used as a symbol outside of fascism

FASCISM TODAY

After WWII, fascism as defined by Mussolini and Hitler's regimes largely fell out of fashion in Europe and North America. Nevertheless, there have been growing fascist movements in Europe and the US. Though many of the economic, social and political drivers of mid-20th-century European fascism were specific to that time and place, fascism's core ideas can still be found in modern populist movements that embrace hardline nationalism, white supremacy and xenophobia (fear of foreigners).

Most modern fascist movements are without official political party representation or state power, so they operate on a social movement framework rather than a political framework. Today's fascist movements also use more nuanced language, for example using the terms 'white separatism' and 'white self-determination'.

WHO WERE THE FOUNDERS?



Marx was born in 1818

Karl Marx

Published by Karl Marx in 1848, *The Communist Manifesto* became the basis of communism. In the manifesto, Marx called for a revolt against capitalism under the motto: "Workers of the world, unite!"

Mussolini was born in 1883

Benito Mussolini

Mussolini coined the term 'fascism' in 1921 when he created the first single-party fascist state. When he became the prime minister of Italy in 1922, Mussolini was able to put his extreme views into practice. 11 years later, Adolf Hitler – a fan of Mussolini – rose to power in Germany with ideologies similar to those Mussolini held.

5 FORMS OF GOVERNMENT

1 DEMOCRACY
INDIA
Meaning 'rule by the people' in Greek, a democratic government allows citizens to vote for political leaders and other major decisions. India is the world's largest democracy, and has been so since 1950.

2 DICTATORSHIP
NORTH KOREA
One person or a small group holds absolute power over citizens. The leader of North Korea is Kim Jong-un, and since 1948 the country has been led by three men from the same family.

3 MONARCHY
QATAR
A monarch, which is usually a king or queen, is given power over a state. Qatar is an example of a hereditary monarchy, having been ruled by the Al Thani family since 1847.

4 SOCIALISM
N/A
In socialist countries, everyone equally owns factors of production, including farms, resources and money. Unlike in communism, it remains possible to own private property. Today, no country is completely socialist.

5 ARISTOCRACY
GREAT BRITAIN
An aristocratic government puts power into the hands of a small, privileged group. An example of this is the British monarchy. The royal family is given some power by the government to approve bills before they become law.

ON THE MAP

Communist countries

Did you know?
China became a communist country in 1949

CUBA

Cuba has been a communist country since 1959, with the Communist Party of Cuba setting its policy. Miguel Díaz-Canel is the country's current president, and first secretary of the Communist Party of Cuba. While the government allows benefits such as education and healthcare being available to all, citizens have limited freedom, as they are forbidden from opposing the government. After 62 years of communism, poverty rates in the country have increased.

Che Guevara is an icon in Cuba for his contribution to the communist uprising

Vientiane, the capital of Laos, flying the national and communist flags together

LAOS

The Lao People's Revolutionary Party (LPRP) is the ruling party of Laos. The communist party altered its policies after the collapse of communist regimes in Europe, but has stayed focused on the values of Marxism. Like many of today's communist countries, the LPRP has significant control over social media use and punishes negative content against the party.

COMMUNISM THROUGH THE YEARS

1848

On 21 February, Karl Marx and Friedrich Engels shared *The Communist Manifesto.*

1917

Led by Vladimir Lenin, the Bolsheviks became the first communist government of the Soviet Union.

1921

On 1 July 1921, the Communist Party of China was created.

DID YOU KNOW? Differences between the communist Soviet Union and capitalist United States led to the Cold War

This communist statue is displayed in Jiangxi Province, China

CHINA

The country is led by the Chinese Communist Party (CCP). With around 85 million members, the CCP is one of the world's biggest political parties, and all elections take place internally. Every five years, 2,000 delegates of the National Congress meet to decide the Central Committee. This has 200 members, who are responsible for electing around 20 members of the political bureau. A select few of these 20 hold the highest authority beside China's leader.

VIETNAM

Governed by the Communist Party of Vietnam, this country has Southeast Asia's fastest growing economy. Between 1975 and the late 1980s, Vietnam only traded with other communist countries. However, after the downfall of the Soviet Union, Vietnam began trading with other countries. Although it is communist, Vietnam has adopted capitalist principles such as support of entrepreneurs, which has helped boost its economy.

Vietnam's largest city is named after communist leader Ho Chi Minh

WHAT IS COMMUNISM?

At its core, communism is an ideology of economic equality through the elimination of private property. The beliefs of communism centre on the idea that inequality and suffering result from capitalism. Under capitalism, private businesses and corporations own all the factories, equipment and resources, called 'the means of production'. These owners, according to communist doctrine, can then exploit workers, who are forced to sell their labour for wages.

The working class, or proletariat, must rise up against the capitalist owners, or bourgeoisie, according to the ideals of communism, and institute a new society with no private property, no economic classes and no profits. Communism differs from socialism, though the two have similarities. Both advocate economic equality and state ownership of various goods and services. Socialism usually works through the existing democratic structures of capitalist countries; most capitalist countries have some socialist characteristics.

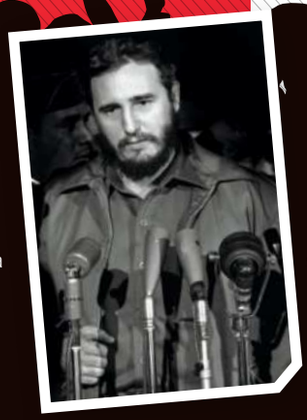
Red was chosen as the colour of communism to represent the blood of those in the battle against capitalism

1924 Lenin died on 21 January, and Joseph Stalin took his place.

1945 Korea was divided during World War II, with North Korea becoming communist.

1947 US president Harry Truman called for communism to be contained.

1959 Fidel Castro took over Cuba to make it a communist state.



1989 The Berlin Wall, which separated West Berlin from the communist East Berlin, was destroyed.

1991 On 25 December, the Soviet Union came to an end, along with communism in the majority of countries.

WELCOME TO THE CRADLE OF CIVILISATION

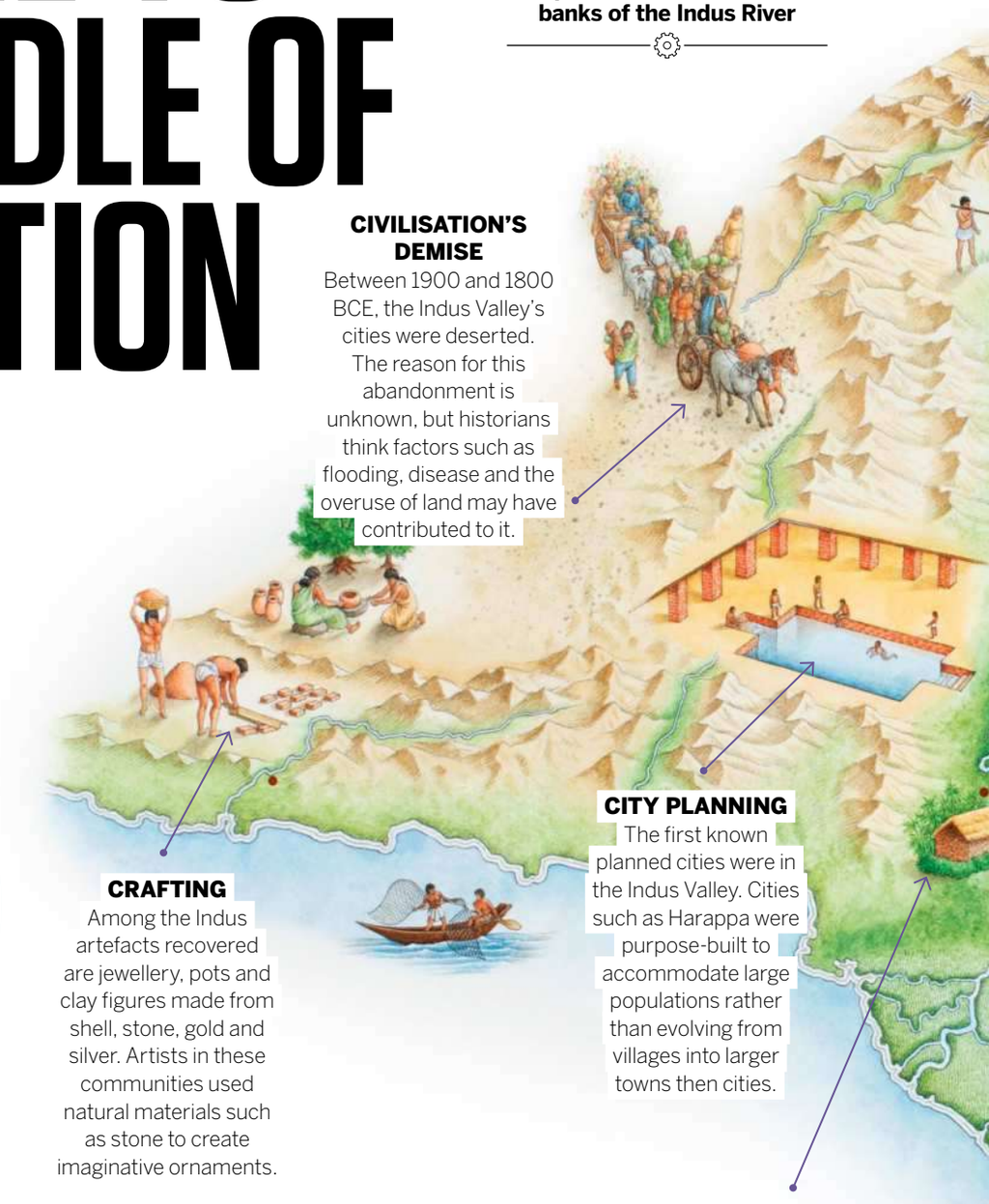
How the ancient society of Pakistan's Indus Valley shaped the modern world

WORDS **AILSA HARVEY**

The Indus Valley Civilisation grew in South Asia during the Bronze Age

ANCIENT LIFESTYLE

Explore ancient life on the banks of the Indus River



CIVILISATION'S DEMISE

Between 1900 and 1800 BCE, the Indus Valley's cities were deserted. The reason for this abandonment is unknown, but historians think factors such as flooding, disease and the overuse of land may have contributed to it.

CRAFTING

Among the Indus artefacts recovered are jewellery, pots and clay figures made from shell, stone, gold and silver. Artists in these communities used natural materials such as stone to create imaginative ornaments.

CITY PLANNING

The first known planned cities were in the Indus Valley. Cities such as Harappa were purpose-built to accommodate large populations rather than evolving from villages into larger towns then cities.

FARMING

To cater for large cities, farmers had to prepare masses of food. Wooden ploughs were pulled by cattle to reduce human labour. Farmers understood that for the best results, seeds should be planted after the river had flooded, producing richer soil.

Urban environments are commonplace in today's age. A majority of countries are home to multiple crowded cities, built to function with dense populations. But when the world's first large civilisation was developing in the Indus Valley around 5,000 years ago, its people created and organised complex cities for the first time. The biggest was home to around 80,000 people.

The Indus River is the longest in Pakistan, and it became a crucial resource at the centre of a growing civilisation. As the water replenished the surrounding crops, the abundance of food and water allowed the Indus Valley to develop and flourish. People became experts at surviving and thriving in this environment. For example, farmers learned how to use the annual flooding to their own advantage by channelling floodwater towards their crops to aid growth.

Did you know?
Lentils, wheat, and barely were grown in the valley

The beneficial geography of the Indus Valley made it a popular location to live, and over time populations boomed. The town planning that arose as a result paved the way for future cities, and today's urban areas share similarities with the Indus Valley. It consisted of many uniform straight roads that created neat city blocks. Wide streets allowed for two cattle-driven vehicles to pass each other, limiting congestion, and drainage systems were installed to maintain hygiene. While many questions are left unanswered about the intricacies of its culture, the logic and management behind one of the oldest known cities display many parallels to today's way of life.

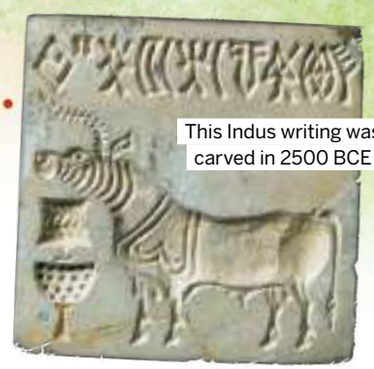
DID YOU KNOW? The Indus language is unknown. Some experts think it was similar to Tamil, which is spoken in India and Sri Lanka

HUNTING

Children were taught to hunt from a young age. Knives, spears and arrowheads have been uncovered that were likely used as hunting tools.

HOUSING

People's houses were made of wood and stone. Wealthy families had larger homes that opened onto courtyards. Houses usually had flat roofs, which could be used for drying out crops. Drains and wells were engineered into homes to provide waste-flushing systems and water access.



This Indus writing was carved in 2500 BCE

EARLY WRITING

More than 400 symbols have been identified from the 3,000 pieces of Indus Valley writings that have been discovered. Indus script is the oldest known form of writing in the Indian subcontinent, preserved as carvings in hardened clay. The exact meaning of these symbols remains a mystery, however, as no one has yet been able to translate them.

The earliest examples of this writing were created between 3500 and 2700 BCE. Carved into the surfaces of pottery are singular symbols. Because they aren't drawn in sequence like thousands of other examples, historians believe this shows the early stages of the Indus script's development. Later examples include sequences of up to 26 shapes and symbols.

SETTLING

Settlements were built along the Indus River. This river stretches through Pakistan, northwest India and Afghanistan. Some 2,000 towns made up the Indus Valley Civilisation.

TRADING

Traders sailed long distances to exchange materials and goods from the Indus Valley. As Indus people were skilled at crafts, handmade stone tools were popular items to sell.

WHEN WAS THE CIVILISATION DISCOVERED?

The abandoned Indus Valley Civilisation was left to ruin for thousands of years. But in 1829 its brick remains were discovered by Charles Masson. Masson was a British soldier who reported seeing mounds of fire-baked bricks in the area. 30 years later, British colonial officials who were monitoring the building of a railway through the Indus Valley discovered more of these bricks.

These were the first pieces of evidence of the lost civilisation, which would lead to in-depth excavations. It wasn't until the 1920s that major excavation began. Archaeologists soon began to uncover the settlements of Harappa and Mohenjo-daro. Before becoming part of Pakistan, this area was the Punjab province of India. The cities beneath the ground were evidence that Indian civilisation began 1,500 years earlier than historians previously thought.

Mohenjo-daro was one of the largest cities of the Indus Civilisation

WHAT WAS THE BATTLE OF THE ALAMO?

The outcome of this two-week battle between Mexican and Texian forces proved pivotal in the Texas Revolution

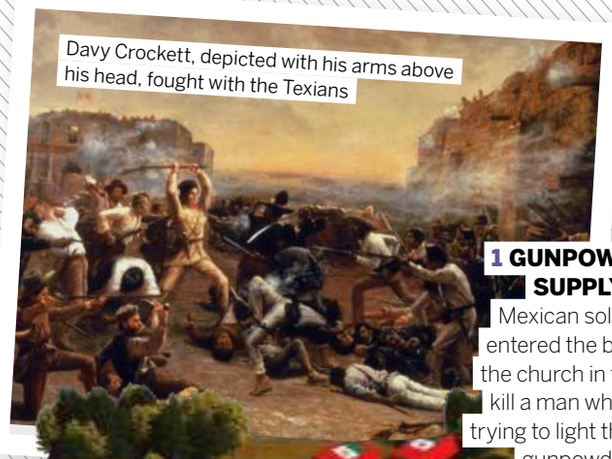
WORDS **AILSA HARVEY**

Between 23 February and 6 March in 1836, the Mexican army surrounded and attacked the Alamo. This old Spanish fort in what is today San Antonio, Texas, was occupied by Texan rebels, who were then called 'Texians'. Many of them had arrived in Texas from the United States and other countries, searching for land and new opportunities after Mexico gained its independence from Spain in 1821. Texas was under Mexican rule at the time of the battle, but its leaders sought independence after the Mexican government became a dictatorship under its new ruler, Santa Anna. Many Texians rebelled against the new government, initiating the Battle of the Alamo.

1,800 to 6,000 Mexican soldiers – their exact number isn't clear – arrived at the fort, which housed a defending force of less than 200. The Mexican army planned to recapture the town and put an end to the Texas Revolution. While the Texians lacked numbers, they displayed great determination.

When the Texians refused to surrender to the thousands of men besieging them, their attackers raised a blood-red flag – this meant 'no quarter'. For everyone in the Alamo, the only two options were victory or death. The battle began at dawn on 6 March and concluded around 90 minutes later.

The Texians suffered a brutal loss at the Battle of the Alamo, but it further motivated them to earn their independence. As they rebuilt their army, they developed a new battle call: "Remember the Alamo!" Their eventual victory came on 21 April at the Battle of San Jacinto.



Davy Crockett, depicted with his arms above his head, fought with the Texians

The Mexicans had numbers on their side

DID YOU KNOW? Defenders at the Alamo requested additional troops, but only 30 arrived before the battle commenced

RECAPTURING THE FORT

Track the offence of the Mexican forces as they surrounded the Texian rebels

2 FINAL POSITIONS
Some of the defending troops were ordered to retreat to the church for a final fight. However, they were outnumbered and lacked weapons.

3 DEFENSIVE RETREAT
The Texian troops took secondary positions inside the fort's buildings.

4 CAPTURE THE CANNON
100 men, led by Colonel Juan Morales, climbed the walls here, taking control of the cannon before the Texians could disable it.

6 SUCCESSFUL ENTRY
After four failed attacks, some of the troops, including General Juan Amador, climbed over the north wall and opened a door for the rest of the attackers.

5 WEST WALL ENTRY
General Martín Perfecto de Cos' men broke windows and doors down with axes as they entered at different sections along this wall.

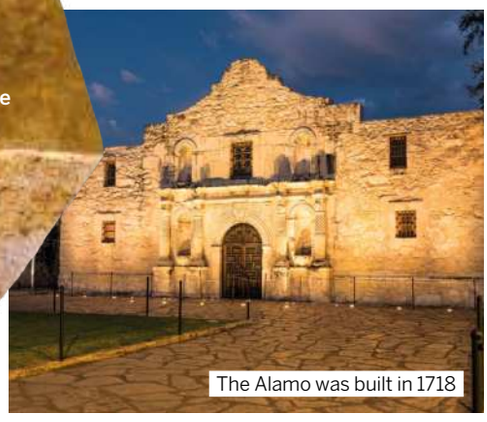
Did you know?
Between 600 and 1,600 Mexican troops were killed

THE LEADERS

The Mexican force was led by Antonio López de Santa Anna, while the Texians followed William Travis. Santa Anna became president in 1833 for his role in Mexican independence. By 1835 he had taken on the role of dictator, planning the invasion of Texas and ousting those who didn't follow him. As commander, Travis was killed with his troops. He rebelled against Mexican rule and became one of the first to sign up to the Texan forces. While surrounded, Travis wrote a letter to the people of Texas: "The enemy has demanded a surrender at discretion... I have answered the demand with a cannon shot and our flag still waves proudly from the walls. I shall never surrender or retreat."

Santa Anna called himself 'the Napoleon of the West'

Travis became a lieutenant colonel in the Texas army at 26 years old



The Alamo was built in 1718

TECHNOLOGY

90 **All about the Internet**
Discover how you can access images and information all over the world – and even beyond – at the click of a button

98 **How heat pumps work**
These machines use cold outdoor air to heat homes

100 **How solar panels work**
From sunlight to light bulbs, this technology creates electricity from a natural resource

102 **21 Simple life hacks**
From food tricks to technology tips, here's how science can offer a helping hand

108 **How a geiger counter works**
These handy devices measure radiation levels, producing an iconic clicking sound

98
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ALL ABOUT THE INTERNET

Discover how you can access images and information all over the world – and even beyond – at the click of a button

WORDS LAURA MEARS

DID YOU KNOW? Across the world, around 4.66 billion people use the internet – nearly 60 per cent of the global population

The internet connects us day and night, wherever we are

The internet is one of the greatest inventions in human history, revolutionising communication and changing the world forever. This vast network connects computers across the world via more than 750,000 miles of cables running under land and sea. It's our fastest method of communication, making it possible to send a message from London, UK, to Sydney, Australia, in just 250 milliseconds. Constructing and maintaining this global link has been a monumental feat of ingenuity.

Created in the United States in the 1960s, the internet was originally a response to the Cold War. President Eisenhower founded the Advanced Research Projects Agency (ARPA) to give a boost to the country's military technology. In need of a secure way to communicate across the country, scientists and engineers started developing a network of linked computers called ARPANET. The original aim was for two computers in different places to be able to share data. By 1969, that dream had become a reality. In the years that followed, the team linked dozens of computers together, and by the end of the 1980s this network contained more than 30,000 machines.

The earliest internet users were mainly researchers and military personnel. The network was complicated, and although it was possible to share files and messages, the interface was not user-friendly. In the early 1990s, a researcher called Tim Berners-Lee started building a layer on top of the internet to make it easier to access; it would become the World Wide Web. His idea was to make information available as pages, written in a shared language called HyperText Markup Language (HTML). Computers would be able to read the language and turn the pages into graphics users could see. Each page would get a unique address, called a Uniform Resource Identifier (URI), and computers would share them using a set of rules called HyperText Transfer Protocol (HTTP). Suddenly, users could see the internet, and they could interact with it without needing to know what was going on behind the scenes.

Since the invention of the World Wide Web, the internet has exploded. In 1993, CERN, where Berners-Lee invented the World Wide Web, made the technology freely available to everyone. This meant that anyone and everyone could add to it, creating their own pages and sharing their own content. Even now, no one owns the internet, although big tech companies wield a lot of its power. It's simply a collection of interlinked networks managed by companies, governments, research organisations and individuals. Google, Microsoft, Amazon and others have changed the way it works, but so too have amateurs creating content from their homes.

Did you know?

Google went public in August 2004, but it was founded in 1998

Since its inception, users have continued to expand the internet, sharing bigger and more complicated content. In 1993, there were fewer than 150 websites on the internet. Now there are almost 2 billion. This ever-growing web of connections has completely changed the way that people live, work and interact.

Pretty much the entire planet is connected to the internet

STEP BY STEP

Wired internet connections are up to ten times faster than wireless

The country with the most internet users is China, with a billion people online

The internet is a giant computer network, linking billions of machines together with underground cables. When you use it, you send messages via those cables asking for data stored on other machines. To make this possible, your computer and the computer you want to talk to need to speak the same language, so there's a set of rules that everyone agrees to use.

These are called TCP/IP, which stands for Transmission Control Protocol/Internet Protocol. TCP/IP makes the internet work a bit like a postal system. There's an address book that contains the identity of every device on the network and a set of standard envelopes for packaging up data. The envelopes must carry the address of the sender, the address of the recipient and details about the information packed inside.

The Internet Protocol (IP) part of the rules explains how the address system works. The Transmission Control Protocol (TCP) part explains how to package and send the data. All computers get an IP address when they connect to the internet, and they're all unique. You can find out yours by typing 'what's my IP' into Google. You'll notice that it's not very human-friendly. It either contains four numbers between 0 and 255, separated by full stops, or eight four-digit sequences separated by colons.

You might also notice that your IP address doesn't stay the same. At home you get your IP address from your internet service provider, but when you're out and about it might come from the Wi-Fi you've connected to in a coffee shop or from your phone company network. To load a website, your machine needs to know the IP address of the web server that contains the data. This is also a long string of letters and numbers, and it might change unexpectedly.

Did you know?
The most popular social network is Facebook

Luckily, there's a second address system that helps you guide your computer to the right place. Known as the Domain Name System, or DNS for short, it gives servers human-friendly names called domains. Your web browser can look these up to find out which IP address to use. Your computer can then make a connection to the server using a three-way handshake.

First, your computer sends a message to the server asking if it's ready to talk. It does this by sending an empty envelope with the word 'synchronise?' written on the front. If the server is ready, it writes 'acknowledge' on a new envelope and sends it back. Finally, your computer completes the connection by sending a third envelope that also says 'acknowledge'.

Now you're ready to start exchanging data. To do this, the server chops the content of the website into small pieces and wraps each one in its own envelope. On the outside it writes its own IP address, your IP address and a sequence number. That number tells your computer how to put the pieces back together. When your computer receives one of these envelopes, it checks it and sends a message back saying 'acknowledge' – this means 'I have received the data and everything looks fine'. If the server doesn't get an acknowledgement back from your computer after a set amount of time has passed, it assumes the envelope got lost or damaged and sends it again.

Once all the data is safely on your computer, the only thing left to do is close the connection. This involves another three-way handshake. One computer sends an envelope that says 'finish'. The other sends back 'acknowledge'. The first one replies with 'acknowledge', and then the connection closes.

"To load a website, your machine needs to know the IP address of the web server that contains the data"

URL DISSECTION

What do the different parts of a web address mean?

2

https://www.livescience.com/20718-computer-history.html

1 5 4 3

1 SCHEME
This tells your browser what rules to use: 'http' is short for HyperText Transfer Protocol. The 's' means secure.

2 AUTHORITY
This tells your browser who you want to talk to. It's usually a domain name, but it can also be an IP address.

3 RESOURCE NAME
This is the name of the resource you want it to access – in this case a web page about computer history.

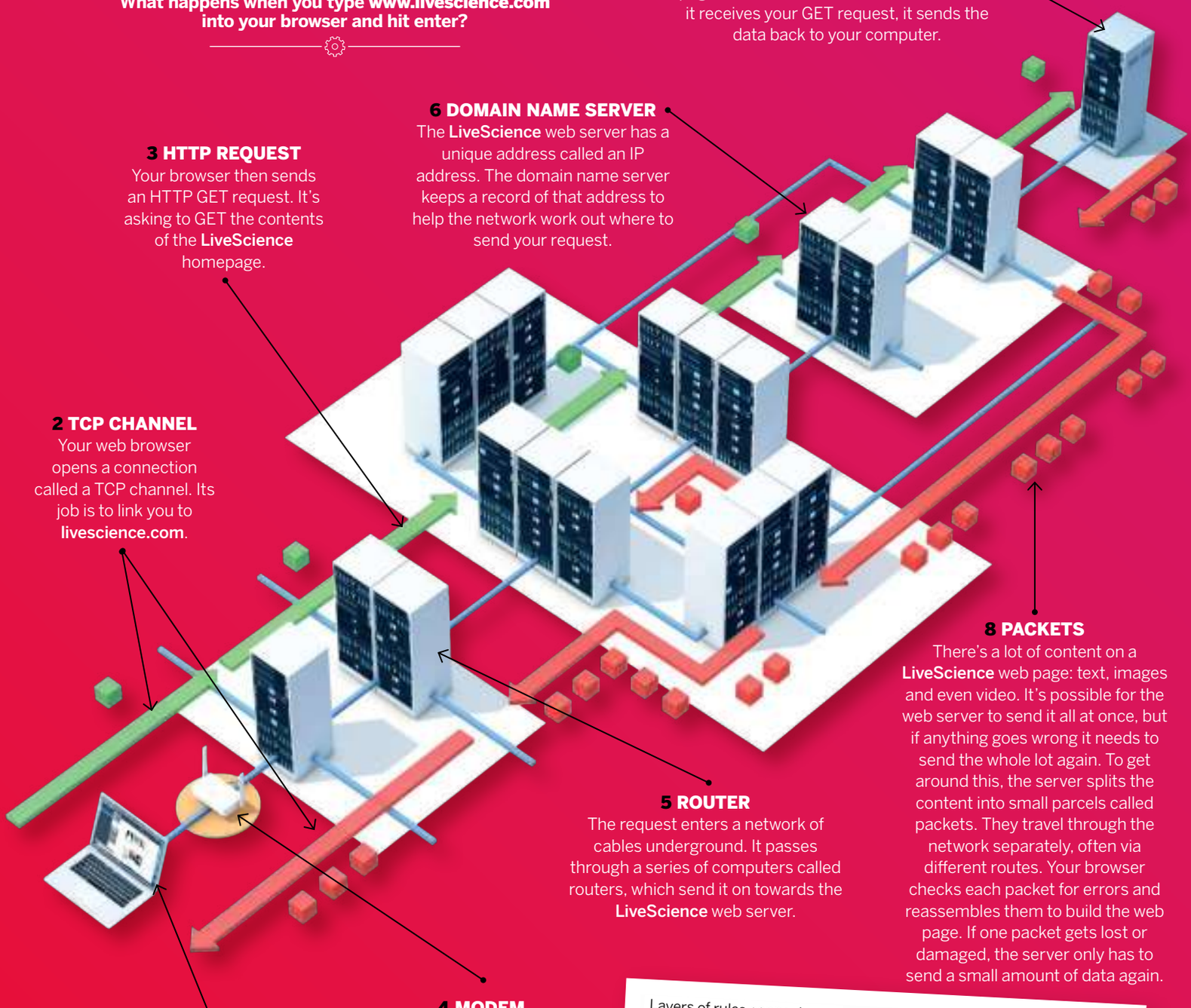
4 PATH TO RESOURCE
Words separated by forward slashes make up the path to the resource you are looking for on the web server.

5 HOSTNAME
This label identifies the computer or server that your request is going to. The convention for web servers is 'www'.

DID YOU KNOW? On average, internet users spend seven hours online each day. Top activities include shopping and social media

HOW DO WEBSITES WORK?

What happens when you type www.livescience.com into your browser and hit enter?



1 USER

When you type the web address, you're telling your browser to make a request to the **LiveScience** web server.

2 TCP CHANNEL

Your web browser opens a connection called a TCP channel. Its job is to link you to **livescience.com**.

3 HTTP REQUEST

Your browser then sends an HTTP GET request. It's asking to GET the contents of the **LiveScience** homepage.

4 MODEM

Your computer passes the digital request to your modem. It takes the request and converts it into an analogue message that can pass through underground cables.

5 ROUTER

The request enters a network of cables underground. It passes through a series of computers called routers, which send it on towards the **LiveScience** web server.

6 DOMAIN NAME SERVER

The **LiveScience** web server has a unique address called an IP address. The domain name server keeps a record of that address to help the network work out where to send your request.

7 WEB SERVER

The **LiveScience** web server stores all the pages and data for **livescience.com**. When it receives your GET request, it sends the data back to your computer.

8 PACKETS

There's a lot of content on a **LiveScience** web page: text, images and even video. It's possible for the web server to send it all at once, but if anything goes wrong it needs to send the whole lot again. To get around this, the server splits the content into small parcels called packets. They travel through the network separately, often via different routes. Your browser checks each packet for errors and reassembles them to build the web page. If one packet gets lost or damaged, the server only has to send a small amount of data again.

AR zone SCAN HERE

Layers of rules connect your devices to the internet


Most of the content on the World Wide Web lives on servers in data centres

WHAT IS THE INTERNET?

This giant network can seem almost ethereal. For the most part we connect to it without wires, sending and receiving data as if from thin air. We can scroll through cat pictures in the middle of a field and stream movies straight from the cloud. But despite that airy feeling, the nuts and bolts of the internet are very solid and very down to Earth. At its core, it's a network of billions of miles of wires end-to-end, and millions of computers.

Your internet connection begins at the modem that's set up in your house. It connects via a wire to a socket in the wall, which links to a box outside. That box connects via still more wires to a network of cables under the ground. Together they convert radio waves to electrical signals to fibre-optic pulses and back again.

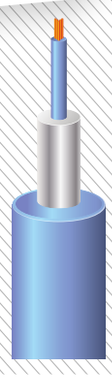
At every connection point in the underground network, there are junction boxes called routers. Their job is to work out the best way to pass data from your computer to the computer you're trying to communicate with. They use your IP addresses to work out where the data should go. The internet is so massive, and changes so rapidly, that it would be impossible for every router to know the IP address of every computer, so each one only cares about its local network. They each maintain an address book called a routing table. It shows the paths through the network to all the local IP addresses.

If a message arrives for a computer that the router doesn't recognise, it passes it on to a router higher up in the local network. If that router doesn't recognise the IP address either, it passes it up again. Eventually, it reaches the top of the network: the backbone. This is the motorway of the internet. Its job is to send traffic around the world, across both land and sea. The data passes from backbone to backbone until it reaches the network closest to its destination. Then it travels down through the layers of local routers until it arrives at the computer with the matching IP address.

These destinations are often data centres, buildings filled with rack upon rack of powerful computers called servers. They contain and manage everything from your social media profile to your email account, your bank and your holiday photographs.

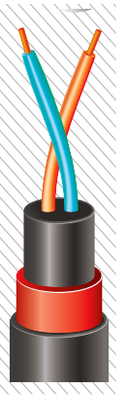
TYPES OF CABLE

Most of the data you send and receive over the internet travels by cable



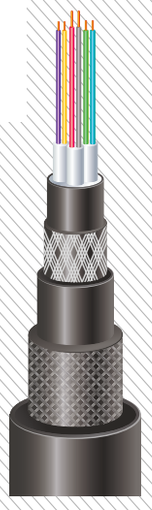
COAXIAL CABLE

Often known as coax, these cables are thick and round, with layers of insulation surrounding a single central core. They can transmit ten megabits of data per second.



TWISTED PAIR

Also known as ethernet cables, twisted pairs were specifically made for connecting computers. Each cable contains four pairs of twisted wires, transmitting ten gigabits per second.



FIBRE

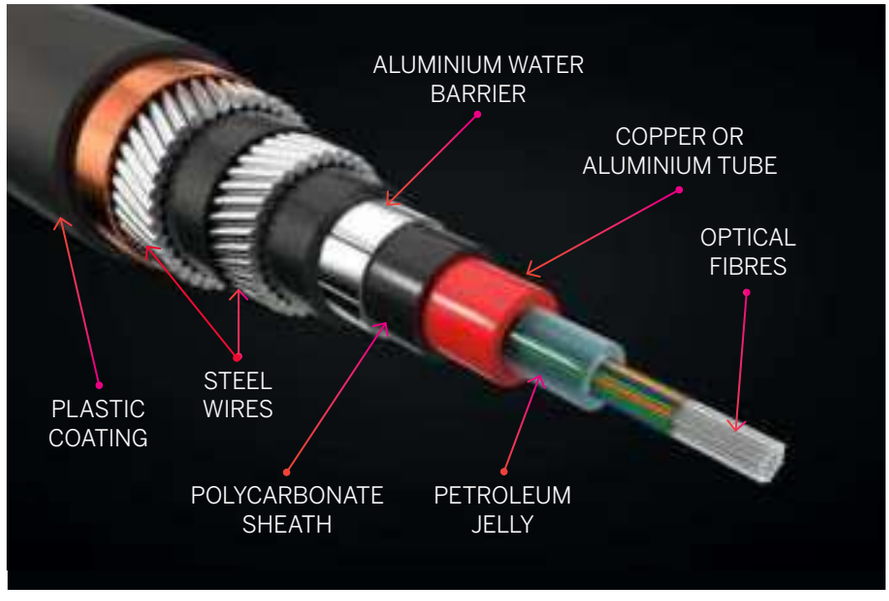
The fastest cables don't carry data as electricity; they carry it as beams of light. At their centres they have a glass core capable of transmitting up to 100 gigabits per second.

Did you know?

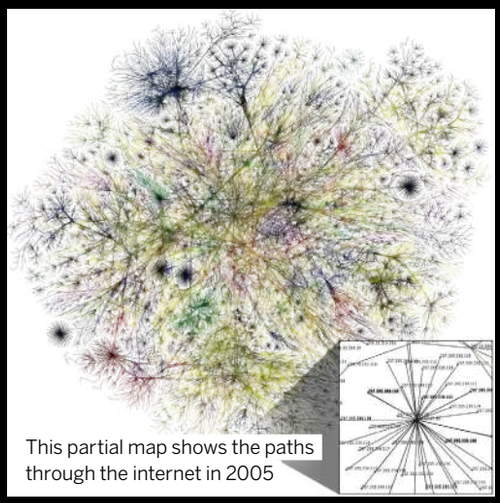
The first subsea cable was buried in 1950

UNDERWATER CONNECTIONS

Have you ever wondered how an email from the US makes its way to Germany? The answer is under the sea. Snaking beneath the world's oceans are miles of submarine optical fibre. The cables run from coast to coast and from continents to islands, connecting everywhere except Antarctica in a literal World Wide Web. About the width of a sausage, each cable contains strands of glass that transmit data as pulses of light. Those strands are wrapped in layers of insulation and buried beneath the seafloor by ships carrying specialist ploughs. This helps to protect them from everything from corrosion to shark bites.



DID YOU KNOW? Google handles over 3.5 billion searches every day. More than half come from mobile phones



This partial map shows the paths through the internet in 2005

This computer was the world's first web server at CERN in 1991

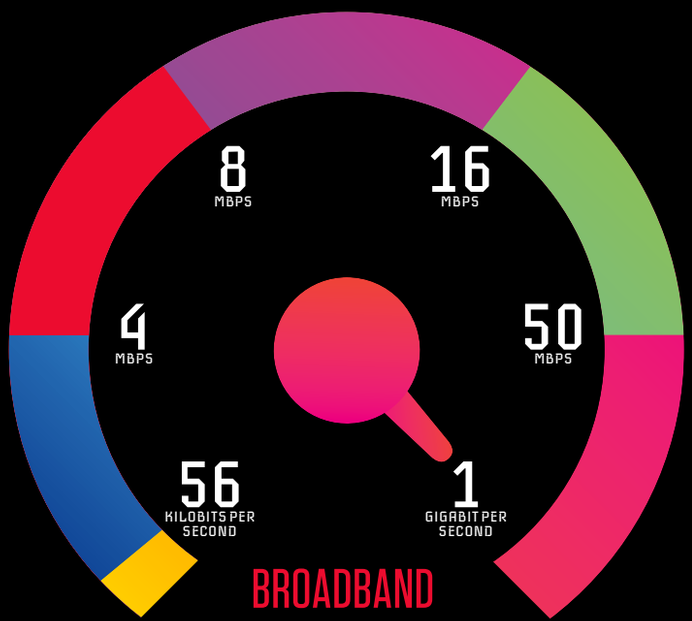
Did you know?

Over 1.8 billion websites exist on the internet

NEED FOR SPEED

When it comes to internet speed, how much data you can download in one second comes down to one thing: bandwidth. To surf the web, check your email and update your social media, 25 megabits per second (Mbps) is enough. But if you want to watch 4K movies, live stream video or play online multiplayer games, you might need speeds of up to 100 megabits per second or more.

Your download speed depends on one main factor: the quality of the underground cables that link you to the rest of the world. Fibre-optic cables send data much faster than their copper counterparts, and your home internet is limited by the infrastructure available in your area. Jersey has the highest average bandwidth in the world. The little British island off the coast of France boasts average download speeds of over 274 megabits per second. Turkmenistan has the lowest, with download speeds barely reaching 0.5 megabits per second.



BROADBAND DOWNLOAD SPEED

5 FACTS SOCIAL MEDIA BY NUMBERS

1 FACEBOOK HAS THE MOST USERS
Each day, 1.9 billion people sign into Facebook. They spend almost an hour there each and together upload more than 300 million photos.

2 YOUTUBE HAS THE MOST VIDEO
When it comes to video, YouTube is the top social media platform. Users add 500 hours of new content every single minute.

3 SIX DEGREES IS THE OLDEST
The first social media platform was Six Degrees. Created in 1996, it was the forerunner to Friendster, Myspace and Facebook.

4 TIKTOK IS THE MOST POPULAR APP
When it comes to social media apps, TikTok was the worldwide favourite in 2020. It had over 850 million downloads.

5 WHATSAPP RULES MESSAGES
This encrypted messaging app is the most popular. It has 2 billion users a month, sharing more than 100 billion messages a day.

SPEED 56 KILOBITS PER SECOND

TIME TAKEN TO DOWNLOAD A MOVIE
3 DAYS, 13 HOURS, 13 MINUTES
In the early days of the internet, data had to travel over copper phone lines. Downloads were painfully slow, making video-sharing practically impossible.

SPEED 4 MBPS

TIME TAKEN TO DOWNLOAD A MOVIE
1 HOUR, 12 MINUTES
3G mobile internet connections provide enough bandwidth to surf the web and send email, but downloading large files takes hours.

SPEED 8 MBPS

TIME TAKEN TO DOWNLOAD A MOVIE
36 MINUTES
Average download speeds for 4G mobile internet allow one user to surf or stream on the move. A strong connection can boost bandwidth to 40 megabits per second.

SPEED 16 MBPS

TIME TAKEN TO DOWNLOAD A MOVIE
17 MINUTES
Standard broadband connections and older satellite connections offer enough bandwidth for a couple of users to browse the web and shop online.

SPEED 50 MBPS

TIME TAKEN TO DOWNLOAD A MOVIE
6 MINUTES
Fibre broadband and modern satellite connections offer speeds fast enough for multiple users to stream video content and play games at the same time.

SPEED 1 GIGABIT PER SECOND

TIME TAKEN TO DOWNLOAD A MOVIE
17 SECONDS
The fastest home fibre broadband allows five or more users to download massive files, watch 4K movies and play competitive games simultaneously.

THE FUTURE OF THE INTERNET


Portable modems and antennae allow satellite internet access in remote locations

In 2019, SpaceX launched 60 satellites. They are set to become part of a constellation of more than 12,000. Known as Starlink, the project aims to bring high-speed internet to every corner of the planet. As it stands, fast internet access is only available in places with fibre-optic cables. In remote locations, communications satellites provide links to the internet, but the connections are notoriously slow. These satellites traditionally fly high above Earth. They sit in geostationary orbit, moving at the same speed as Earth's rotation. They have a wide view of Earth's surface and always hover over the same point on the ground. This makes it easy for satellite dishes to find them. The downside is that getting data to them takes time.

SpaceX wants to change that by surrounding Earth in a cage of low-orbiting satellites. Individually, they won't see as much of Earth's surface, and they won't always hover above the same spot, so there will need to be thousands of them to ensure complete coverage of the globe. But because they fly low, it will cut the time it takes for a signal to travel from the ground to space and back again.

Achieving this is no mean feat. The closer a satellite is to Earth, the more drag it will experience from the edges of the atmosphere. To get around this, SpaceX has designed the satellites to look like sharks, with a knife-like edge that cuts through the wind. Each one weighs just 250 kilograms and works a bit like a router. Its job is simply to receive signals, work out where they're going and pass them on. On the ground, users will have special dishes that lock on to whichever satellite is closest. But the project is not without controversy.

> **"SpaceX wants to surround Earth in a cage of satellites"**

Each satellite has a solar array that sticks out like a wing. At sunrise and sunset, these catch the light, making them glint like shooting stars. As the constellation moves overhead, it leaves streaks on telescope images, obscuring the stars and planets behind. SpaceX has been working with astronomers to minimise the impact by shading and tilting the satellites to reduce the light reflected back towards Earth.

The satellites also pose a potential threat to other orbiting objects. They're already responsible for over half of the close encounters in Earth's orbit, and that proportion is only set to rise. In December 2021, the Chinese government lodged a formal complaint with the United Nations after two near misses with the Chinese Space Station Tiangong. And with at least 11 other companies already entering the satellite constellation race, space is likely to get more complicated and more crowded in years to come.


Long-exposure images show Starlink satellites streaking across the night sky

HOW STARLINK WORKS

Can a network of satellites provide high-speed broadband to every corner of the globe?

1 GROUND STATION
Fibre-optic cables send data from the internet to the ground station.

2 LOW ORBIT
The ground station sends the data into space, past objects in low-Earth orbit, like the ISS.

3 UPLINK
The nearest Starlink satellite receives data from the ground station.

4 SATELLITE NETWORK
The data travels through the Starlink network until it reaches the satellite closest to the user.

5 HIGHEST ORBIT
The signal never travels higher than 621 miles, avoiding other communications satellites.

6 DOWNLINK
The satellite sends the data signal back down to Earth.

7 SATELLITE DISH
A satellite dish receives the signal anywhere in the world.

8 MODEM
A modem connected to the satellite links the user's devices to the internet.

CONNECTING THE WORLD

1966
The US Defence Agency funded the Advanced Research Projects Agency Network, or ARPANET. Its primary mission was to create the internet.

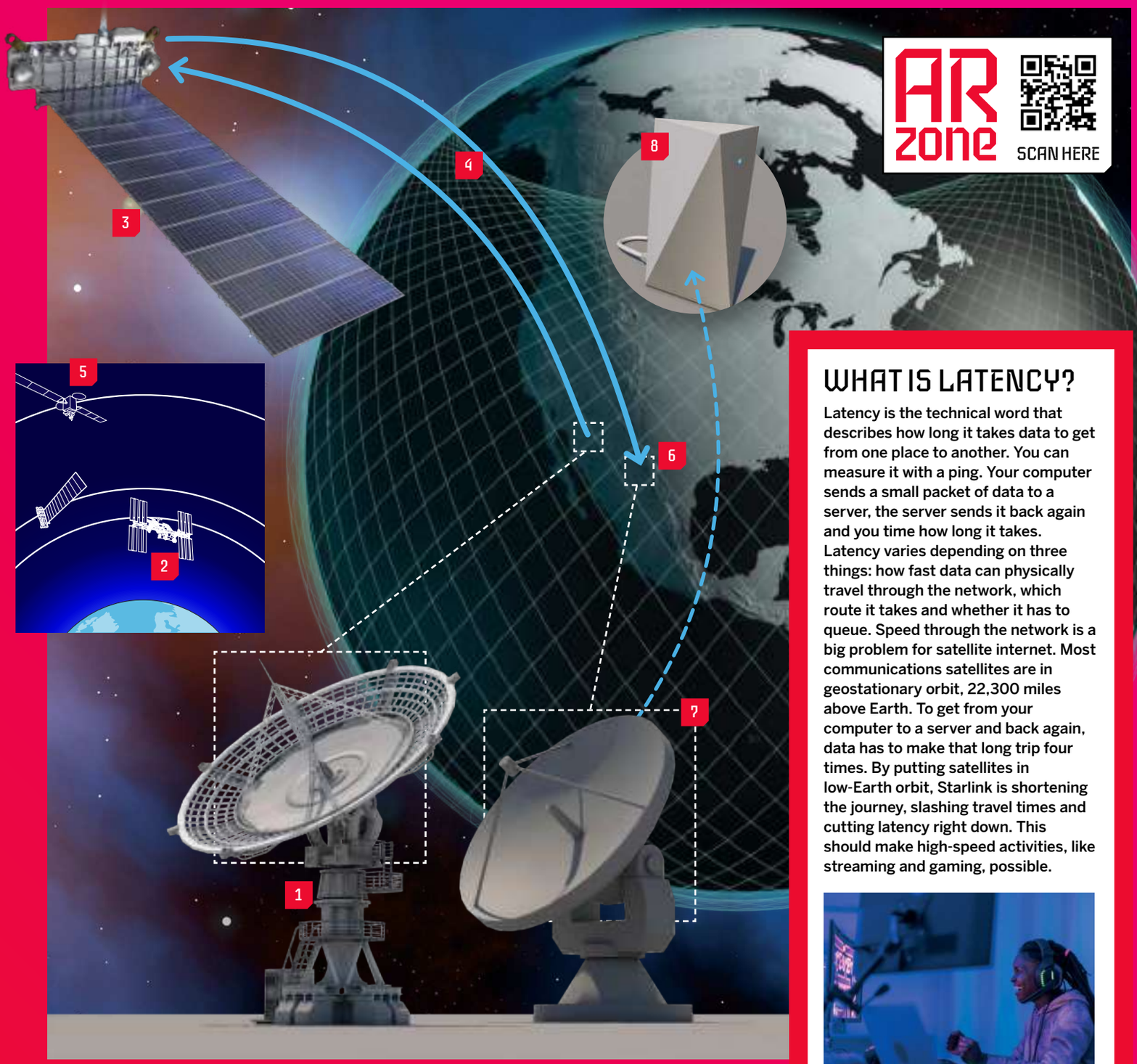
1969
Researchers sent the first ARPANET message. It was supposed to say 'login', but the system crashed after the letters 'lo'.

1971
Ray Tomlinson invented email and email addresses. He chose to put the @ symbol between the username and the location.

1983
ARPANET split into two networks: one for military communication and another for everything else. This was the birth of the internet.

1989
Tim Berners-Lee invented the World Wide Web, a way to connect documents on the internet together with hyperlinks for ease of use.

DID YOU KNOW? The average person spends 2 hours and 22 minutes a day looking at social media



WHAT IS LATENCY?

Latency is the technical word that describes how long it takes data to get from one place to another. You can measure it with a ping. Your computer sends a small packet of data to a server, the server sends it back again and you time how long it takes. Latency varies depending on three things: how fast data can physically travel through the network, which route it takes and whether it has to queue. Speed through the network is a big problem for satellite internet. Most communications satellites are in geostationary orbit, 22,300 miles above Earth. To get from your computer to a server and back again, data has to make that long trip four times. By putting satellites in low-Earth orbit, Starlink is shortening the journey, slashing travel times and cutting latency right down. This should make high-speed activities, like streaming and gaming, possible.

Low latency is crucial in preventing lag in online games

1991

The first-ever website went live. You can still visit it today at **info.cern.ch**.

1992

Dial-up brought the internet into people's homes for the first time, using telephone lines to download data up to 56Kbps.

2000

The introduction of asymmetric digital subscriber line (ADSL) broadband increased home internet speeds to 512Kbps.

2008

The first fibre broadband made 50Mbps download speeds possible, paving the way for streaming.

2009

The introduction of 4G internet brought broadband-like download speeds to mobile phones.

HOW HEAT PUMPS WORK

These machines use cold outdoor air to heat homes

WORDS **SCOTT DUTFIELD**

Did you know? Peter von Rittinger created the first heat pump system

Around 85 per cent of homes in the UK are equipped with a gas boiler, totalling around 26 million boilers nationwide. Each one of these boilers expels around 3.54 tonnes of carbon dioxide into the atmosphere annually from burning natural gas. Collectively, the UK's 26 million boilers pump out 92 million tonnes of carbon dioxide each year. The UK government has committed to zero emissions by 2050, and with this in mind there are calls for a ban on gas boilers as soon as 2025. But what could replace them?

Ready to take on the role are heat pumps. An air-to-air heat pump is a piece of machinery that extracts the energy from cold air and converts it into heat, which can be circulated throughout the home and heat water. Heat pumps are powered by electricity and use a liquid called a refrigerant to take thermal energy from outside, turn that energy into heat and then expel it indoors. Commonly used refrigerants are R134a and R-410A, which have incredibly low boiling points – R134a boils at around -26 degrees Celsius and R-410A at around -48 degrees Celsius. This means that most normal outdoor temperatures can cause them to boil into a hot vapour that can be pressurised to expel heat.

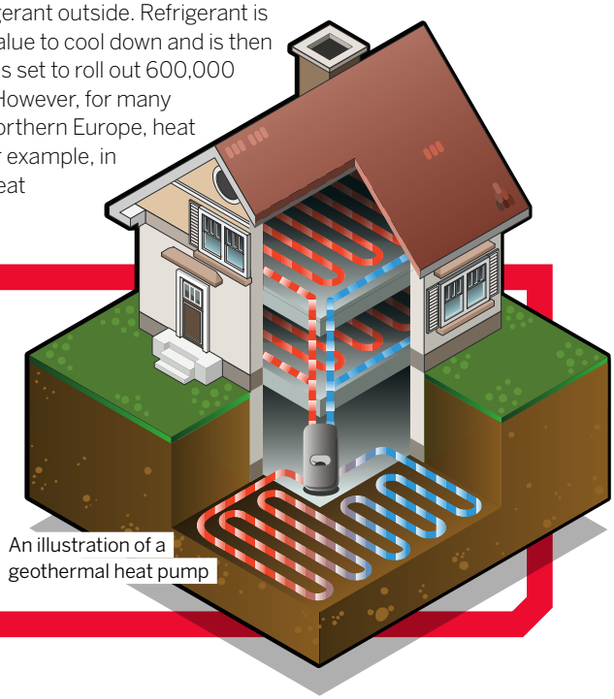
Similarly, when the temperature outside is hotter than indoors, these systems can quickly be transformed into air conditioners. The system is reversed: rather than forcing hot, vaporised refrigerant through pipes inside the house, a reversing valve diverts the refrigerant outside. Refrigerant is passed through an expansion value to cool down and is then fed inside. The UK government is set to roll out 600,000 heat pumps per year by 2028. However, for many countries across Central and Northern Europe, heat pumps are well-established. For example, in Sweden more than 1.9 million heat pumps are already in operation.

Above: The outdoor unit of an air-to-air heat pump

Above left: Heat pumps can also be used to heat or cool large commercial buildings like offices

HOT ROCKS

Air-to-air heat pumps are not the only home heating method. Water source heat pumps work similarly to air-to-air heat pumps, but extract heat between tanks of water rather than ambient air. Geothermal heat pumps, on the other hand, use stored solar energy trapped in the ground. This type of heat pump system uses a series of connected pipes called a loop, which is buried underground. As the cool refrigerant passes through the loop it's heated by the trapped solar energy and then fed into the compressor. Geothermal heat pumps are particularly efficient as ground temperatures are relatively constant throughout the year, regardless of season.

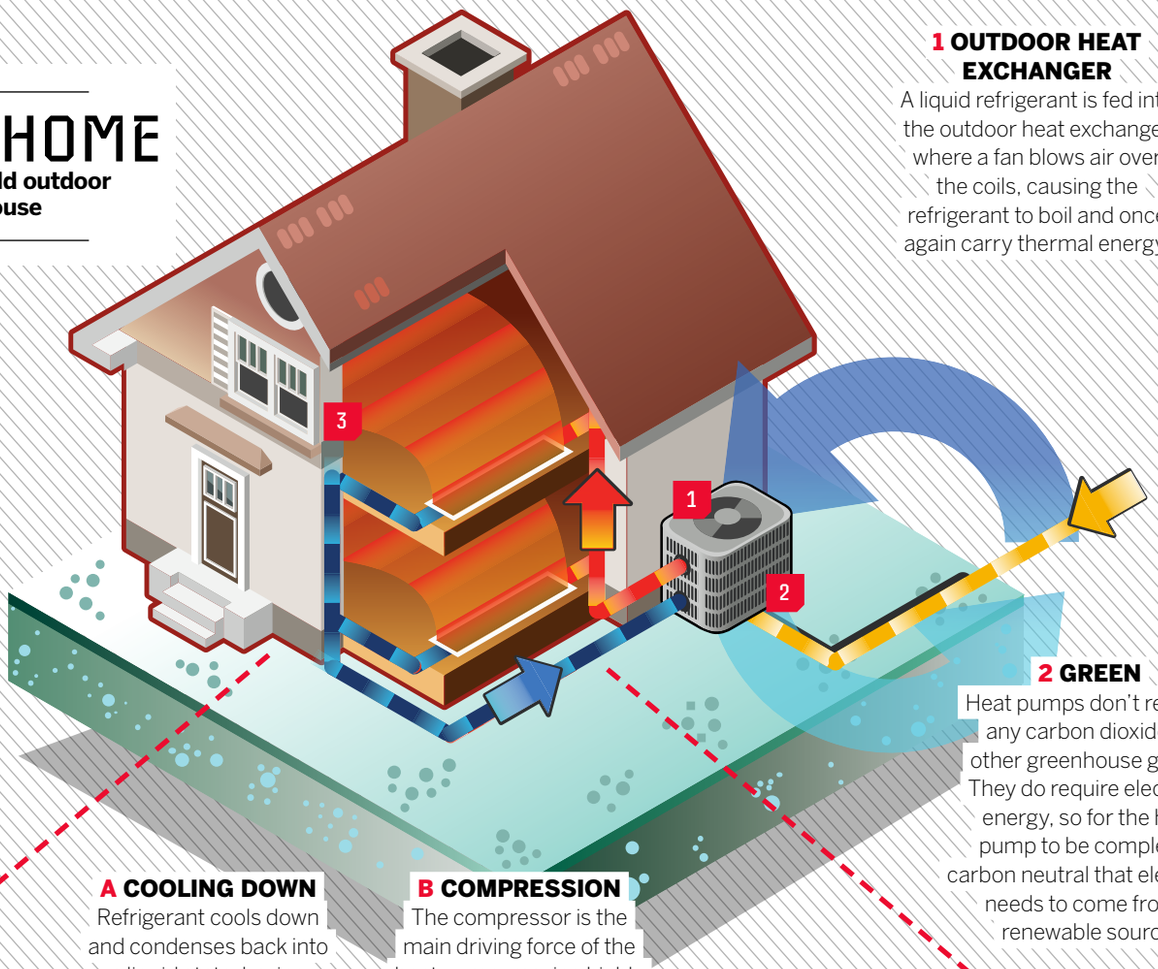


An illustration of a geothermal heat pump

DID YOU KNOW? Heating makes up 40 per cent of the UK's total energy consumption

HEATING A HOME

How heat pumps use cold outdoor air to heat up a house



1 OUTDOOR HEAT EXCHANGER
A liquid refrigerant is fed into the outdoor heat exchanger where a fan blows air over the coils, causing the refrigerant to boil and once again carry thermal energy.

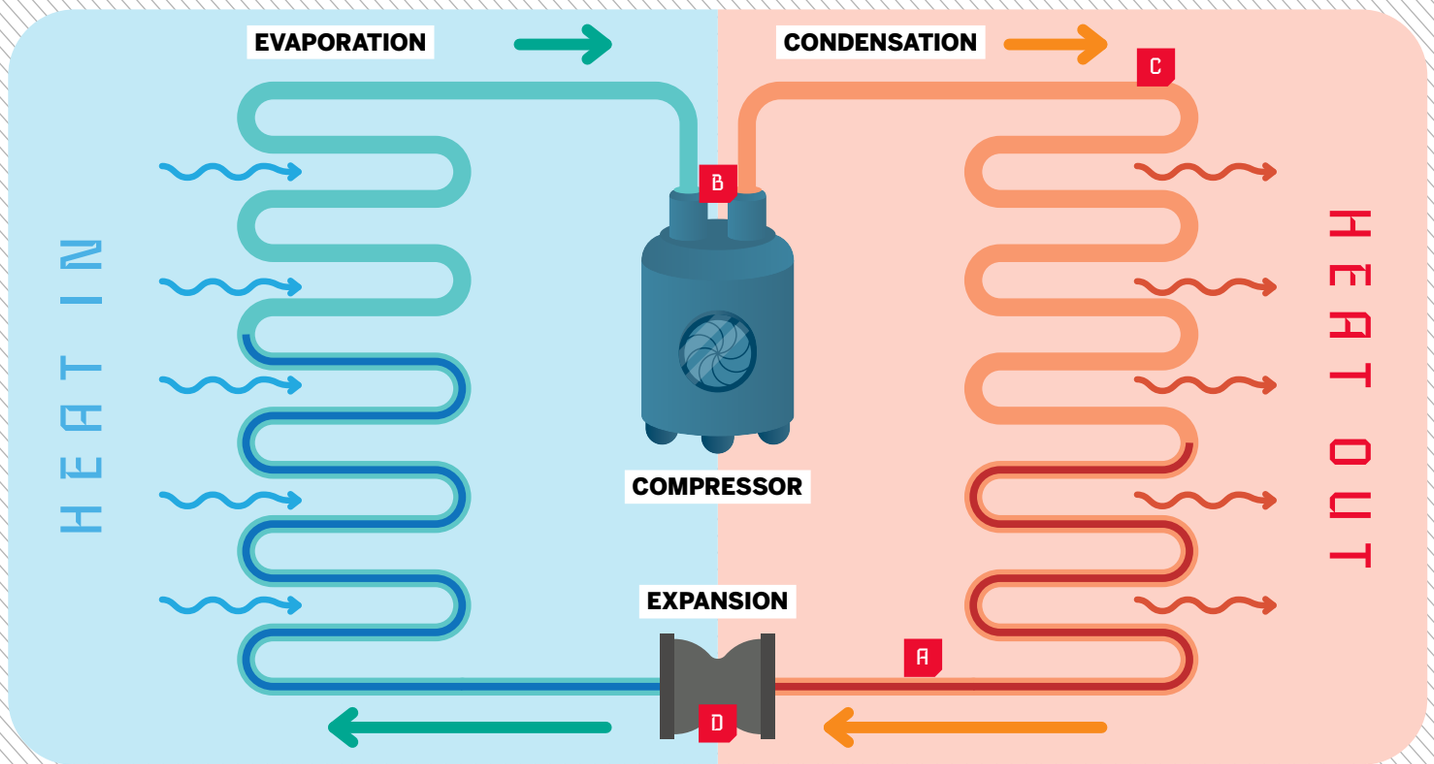
2 GREEN
Heat pumps don't release any carbon dioxide or other greenhouse gases. They do require electrical energy, so for the heat pump to be completely carbon neutral that electricity needs to come from a renewable source.

3 INDOOR HEAT EXCHANGER
Cool air within the home moves over the indoor heat exchanger, removing thermal energy and transferring heat to the rest of the room.

A COOLING DOWN
Refrigerant cools down and condenses back into a liquid state, having expelled the majority of its thermal energy.

B COMPRESSION
The compressor is the main driving force of the heat pump, moving highly pressurised vapour through the system.

C INDOOR HEAT EXCHANGER



D EXPANSION VALVE
As the liquid passes through the expansion valve, it expands, decreasing the pressure its under. This allows the refrigerant to boil at much lower temperatures.

HOW SOLAR PANELS WORK

From sunlight to light bulbs, this technology creates electricity from a natural resource

WORDS **AILSA HARVEY**

They can be found adorning roofs in a shiny, blue sheet, or lined up in rows as part of large energy farms. Solar panels were invented in 1954 but are becoming increasingly popular today as an environmentally friendly alternative to producing energy from fossil fuels.

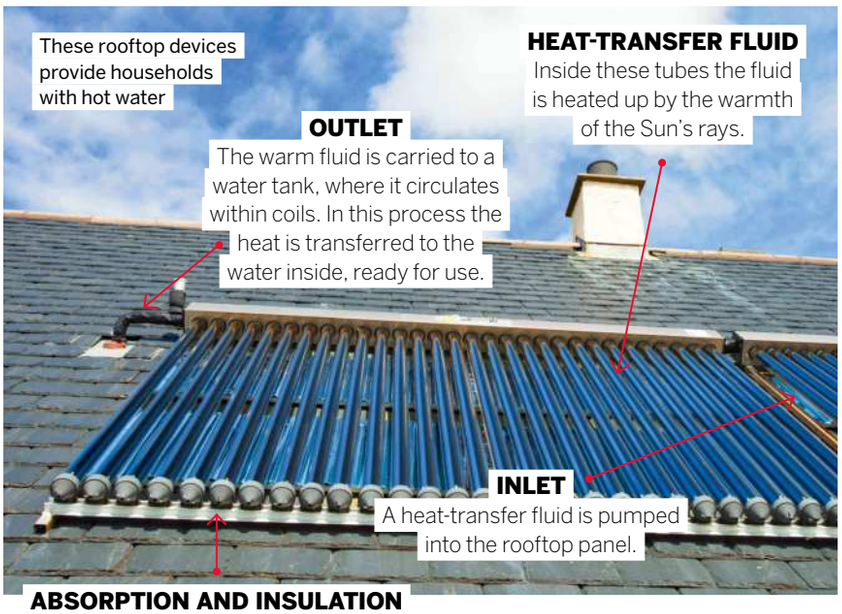
To create electricity these panels use the photons from sunlight to knock electrons free from atoms, producing a flow of electric current. Each panel consists of many smaller photovoltaic cells. These are usually made of two layers of silicon, a semiconducting material. The electricity produced in these cells is then converted into a usable form and carried in wires towards electrical appliances.

In 2020 there were around 500 solar farms in the UK alone

Around 900,000 houses in the UK have solar panels installed

PANEL TYPES

All solar panels work to make the Sun's energy usable, but different types convert this in different ways. While photovoltaic panels create electricity, solar thermal panels use the Sun's heat to warm up water by connecting to a building's boiler. After trapping the heat within the solar panels, a heat-transfer fluid – made of water and glycol – transports the heat energy between the two appliances.



These rooftop devices provide households with hot water

OUTLET
The warm fluid is carried to a water tank, where it circulates within coils. In this process the heat is transferred to the water inside, ready for use.

HEAT-TRANSFER FLUID
Inside these tubes the fluid is heated up by the warmth of the Sun's rays.

INLET
A heat-transfer fluid is pumped into the rooftop panel.

ABSORPTION AND INSULATION
A dark surface made of copper, aluminium or steel absorbs the heat, while an insulating layer below prevents it from escaping.

5 BENEFITS OF SOLAR PANELS

1 SUSTAINABLE ENERGY
Energy from fossil fuels is limited to the finite amount of resources on Earth, but solar energy can continue for as long as the Sun keeps shining.

2 MINIMAL MAINTENANCE
Solar panels should only require cleaning occasionally. As the technology has minimal moving parts, they can last for long periods without breaking down.

3 EXTRA ENERGY STORAGE
Any extra solar electricity generated that isn't used can be exported to the local electricity company to be used later.

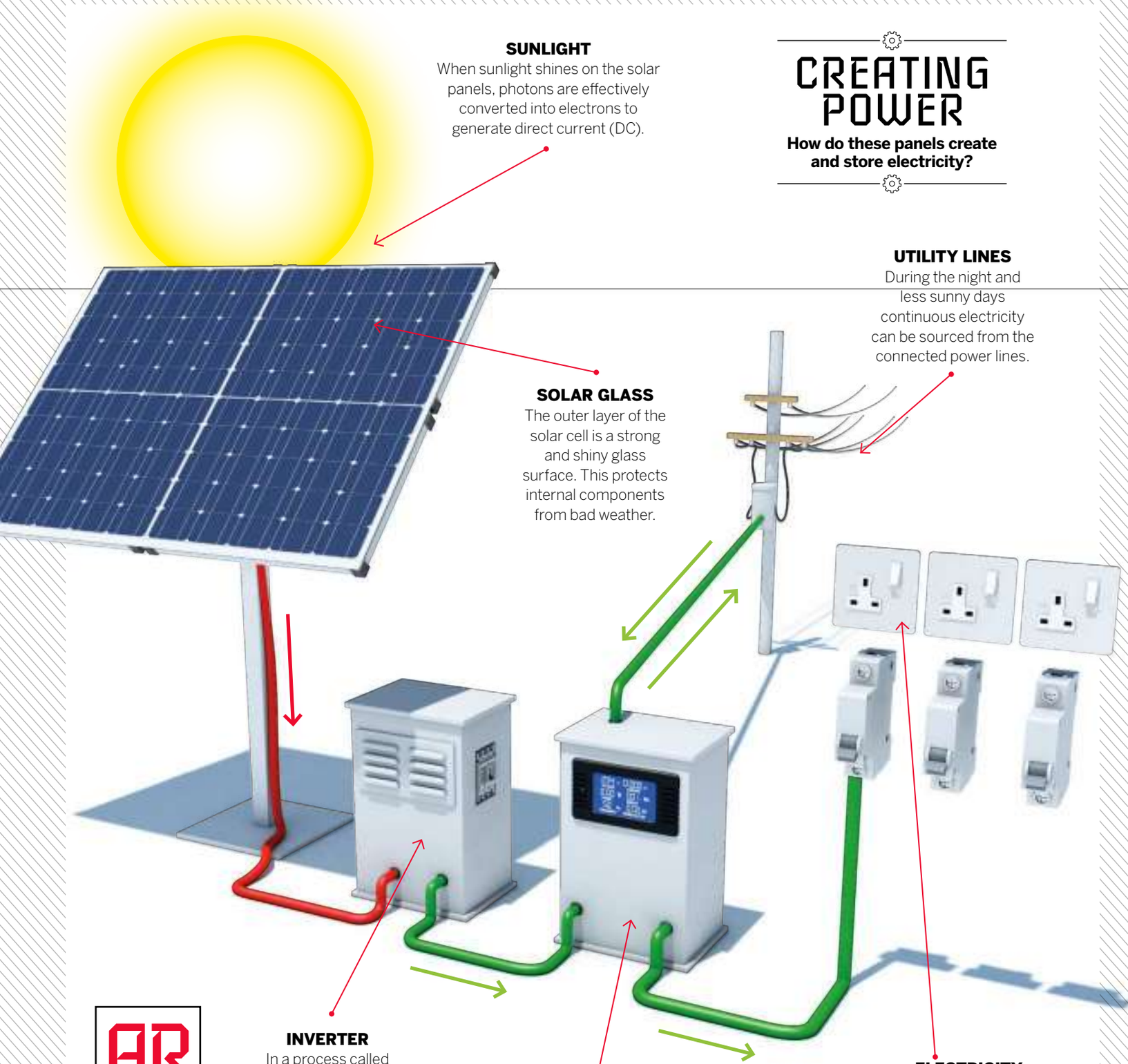
4 OFF THE GRID
For extremely remote locations without access to electrical grids, solar panels are a useful solution. As long as there is sunlight, electricity can be produced right there at the site.

5 REDUCED EMISSIONS
Solar panels produce energy without releasing as many harmful emissions. The average solar panel will save over 900 kilograms of carbon dioxide from being released each year.

DID YOU KNOW? The solar energy that hits Earth in one hour is enough to meet global power needs for a whole year

CREATING POWER

How do these panels create and store electricity?



SUNLIGHT
When sunlight shines on the solar panels, photons are effectively converted into electrons to generate direct current (DC).

SOLAR GLASS
The outer layer of the solar cell is a strong and shiny glass surface. This protects internal components from bad weather.

UTILITY LINES
During the night and less sunny days continuous electricity can be sourced from the connected power lines.

INVERTER
In a process called 'conditioning', the DC is turned into an alternating current (AC) by the inverter.

ELECTRIC METER
The amount of electricity stored is recorded by the meter. Any excess energy that won't be used immediately can be stored in batteries or sent to an electricity company.

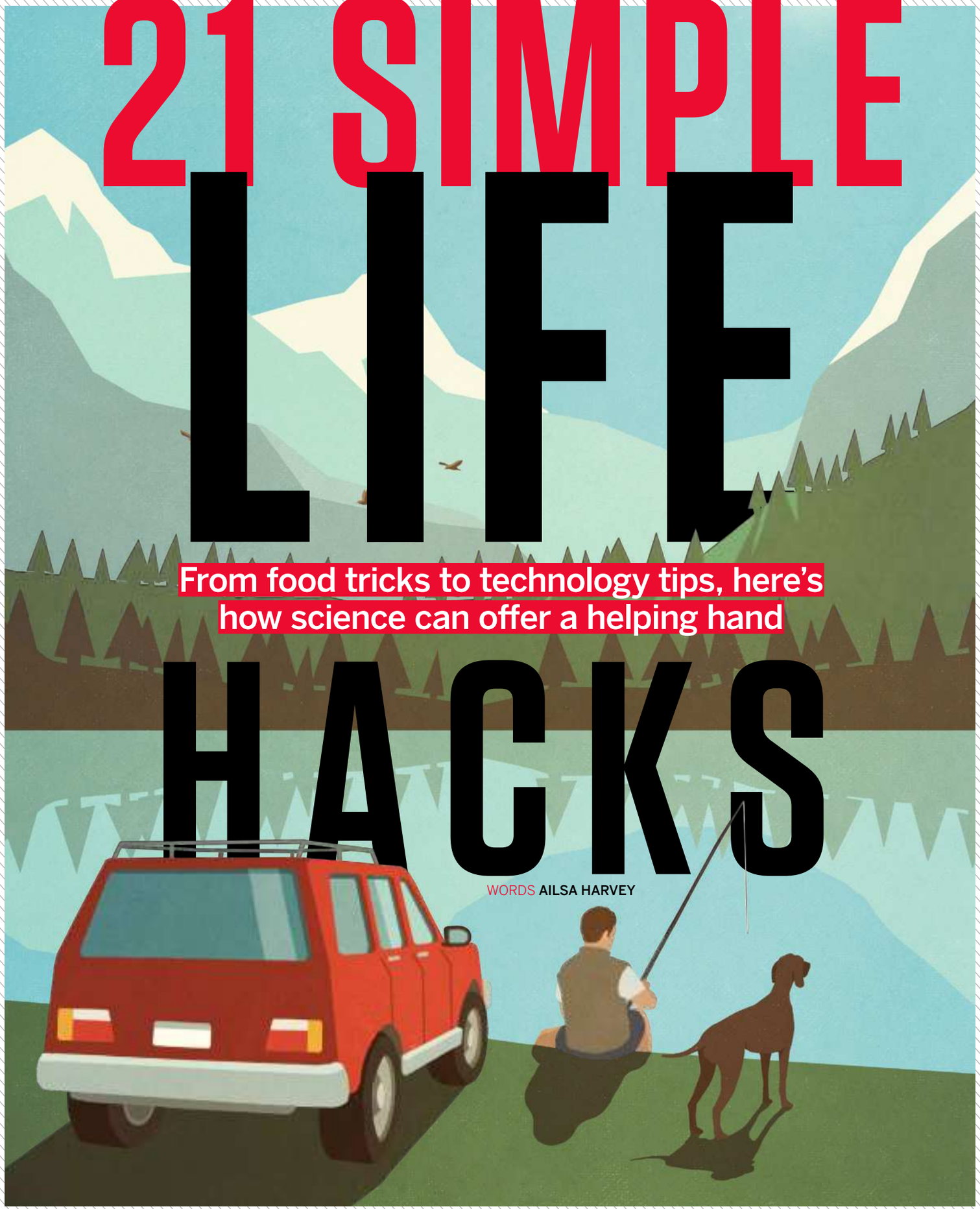
ELECTRICITY USAGE
When electricity is turned on it flows through wires within the walls of the house, towards plug sockets, to power appliances.

AR zone

SCAN HERE

21 SIMPLE LIFE HACKS

From food tricks to technology tips, here's how science can offer a helping hand



WORDS **AILSA HARVEY**

DID YOU KNOW? The synthetic ingredients in chewing gum don't decompose

01

EASY EGG WHITES

Baking recipes often ask you to separate egg yolks from the whites, which can sometimes be easier said than done. An uncooked egg can be tricky to handle, with the slippery yolk hard to grab hold of. A common technique involves moving the yolk between the two halves of the broken shell and letting the whites run into a bowl, but this can be messy. To make this ordeal a simple process, all you need is an empty plastic water bottle. First, crack the entire egg, or eggs, into a shallow bowl. Take the open plastic bottle and squeeze it slightly to remove some of the air. Place the opening over the yolk you want to remove and release the bottle slightly to suck it up. The yolk will sit in the neck of the bottle, leaving the whites separated in the bowl.

The bottle can suck up the yolk

Did you know?

All of an egg's cholesterol is in the yolk

Chewing gum has an insoluble gum base

02

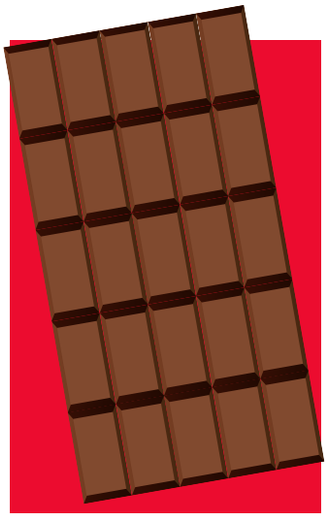
STICKY GUM CLEANUP

If you've ever accidentally stepped on or sat in chewing gum, you'll know the difficulty of trying to remove this rubbery mess. To reduce the stickiness and avoid pulling it apart string by string, apply an ice cube to harden the gum – then you can peel the gum away from your clothing with ease. If the gum is stuck in your hair, peanut butter works to reduce stickiness and the likelihood of needing a spontaneous haircut. To remove it, you need to completely cover the gum with peanut butter using your fingers or a spare toothbrush. The oils in the peanut butter make the base of the chewing gum stiffen and come loose from the hairs.

03

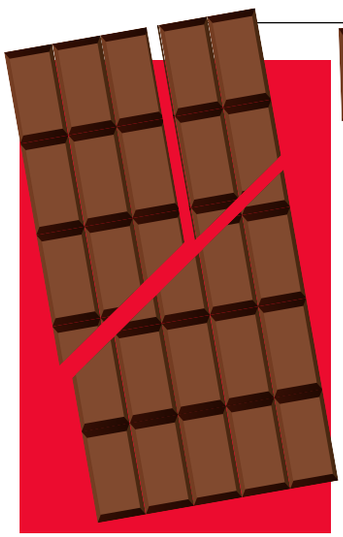
THE INFINITE CHOCOLATE TRICK

Take an extra piece of chocolate without anyone noticing

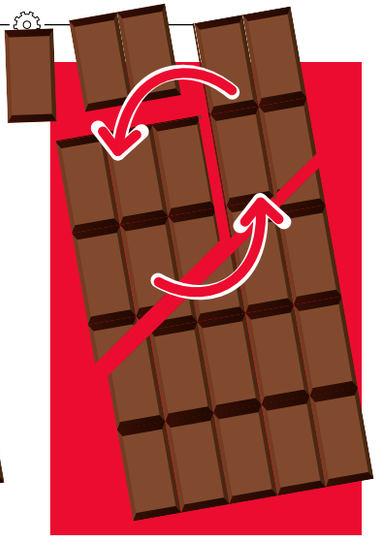


1 SWEET TREAT
Take a chocolate bar that is made up of five by five blocks.

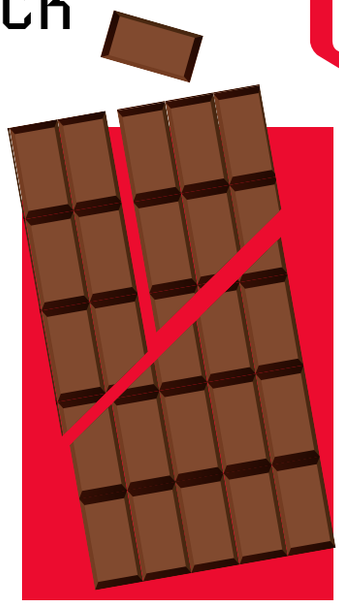
"Now you have a chocolate bar... and your spare piece"



2 CHOPPING UP
Make a diagonal cut from just below the second block from the bottom on the left side to just above the third block on the right side. Take the top piece and cut it vertically after the third block from the left on the top row.



3 REARRANGE
Cut the top-left block off, and the two blocks to the right of it on the same row, but keep these two joined together. Move this single block and the pair away from the bar and swap around the two remaining pieces above the diagonal cut.



4 BONUS SQUARE
Place the larger of the two small pieces back in the top-left corner of the chocolate bar. Now you have what looks like a five-by-five chocolate bar... and your spare piece.

QUICK PHONE HACKS

04 Using a few common items with a smartphone, you can maximise your phone's features. For example, if you ever find yourself with just a smartphone torch for light, you can turn this focused light into a lamp. To do this, you just need a full water bottle. Place your phone torch so that the light is shining upwards, and balance your water bottle – with any labels taken off – so that it covers the light. The water in the bottle bends the light in different directions to illuminate more of your surroundings at once.

05 You can also maximise your phone's speaker volume and audio quality. For the former, all you need to do is place the phone into a bowl or glass while playing music. While the music quality won't be exceptional, the volume will increase as the sound waves bounce against the bowl before being projected up and out.

06 To improve the quality of audio in voice or video recordings and to block out background noise, cover the smartphone's microphone. At a concert, for example, this will block out the background noise and screams from the audience and focus more on the singer's sound.

For one of these phone hacks, all you need is a smartphone and a water bottle

07

TURN AAA BATTERIES INTO AA

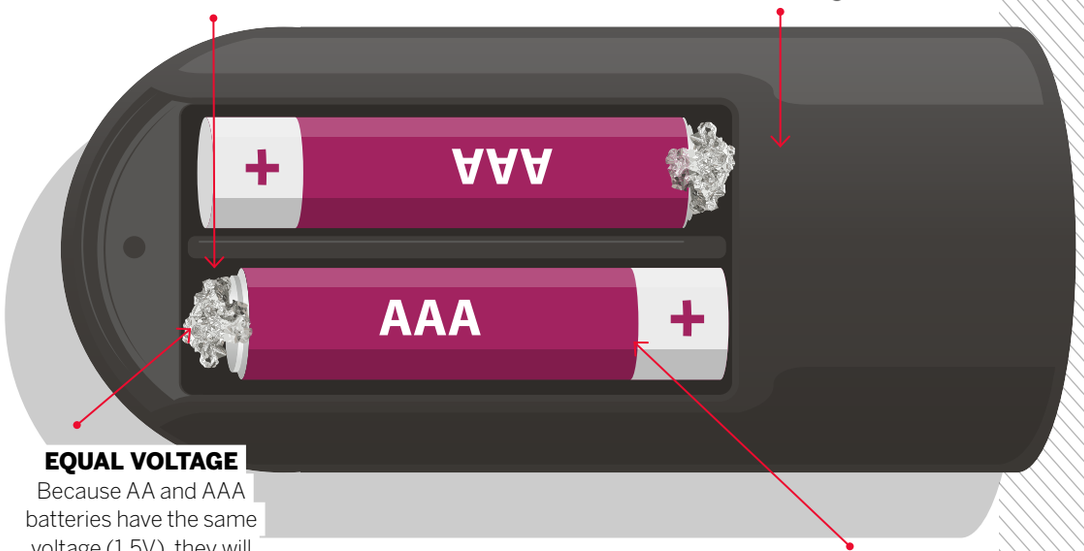
Do you always have the wrong type of batteries lying around? Here's how to make your own AAs

FOLDING FOIL

Fold two pieces of foil into small ball shapes so that they fill the gaps. At the right size they will be in contact with the springs in the battery compartment and the end of the AAA batteries.

AA APPLIANCE

While AAA batteries can power AA appliances, the larger size of AA batteries allows them to deliver a greater current, so the correct battery should be used for long-term use.



EQUAL VOLTAGE

Because AA and AAA batteries have the same voltage (1.5V), they will work in the same appliances as long as the metal foil remains in contact with the battery terminal to pass the electric current.

SAFETY

Because AA and AAA batteries have a low voltage, they can be changed relatively safely. However, if you notice anything unusual you should remove the batteries and foil.

AAA BATTERY

AAA batteries are smaller than AA batteries. When they are placed in an AA battery compartment, significant gaps are left.

08

BATTERY BOUNCE TEST

For those who forget to throw away used batteries immediately, it can be impossible to know just by looking at them which batteries have been used and which are new. However, science can help you answer this question. When a conventional battery is unused, the molecules in its outer zinc layer are randomly arranged. This means if the battery is dropped, the molecules can move to absorb some of the kinetic energy and prevent it from bouncing too much. For used batteries, the zinc has been converted into zinc oxide and the molecules line up more uniformly. The kinetic energy is passed through the molecules and creates a recoil, pushing the battery back off the ground. If you ever need a hint as to which batteries have previously been used, dropping them from the same height could provide the answer. Those that bounce higher are likely to be used.

Batteries look the same from the outside whether they are new or completely depleted

Did you know?

3 billion batteries are bought in America each year

COOL COOKING HACKS

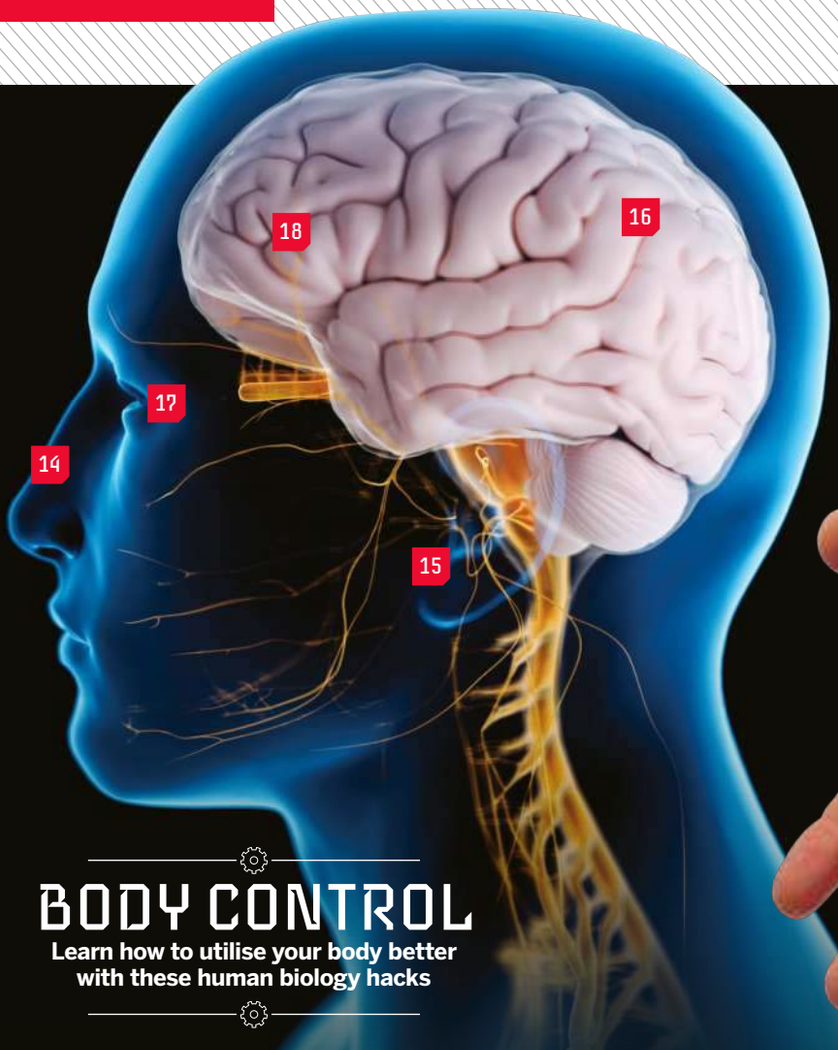
09 IDENTIFY BAD EGGS
If you've had eggs in the fridge for a while and are unsure if they have gone off or not, simply put them in a bowl of cold water. If they sink and lie flat, they're good to eat. Bad eggs will float.

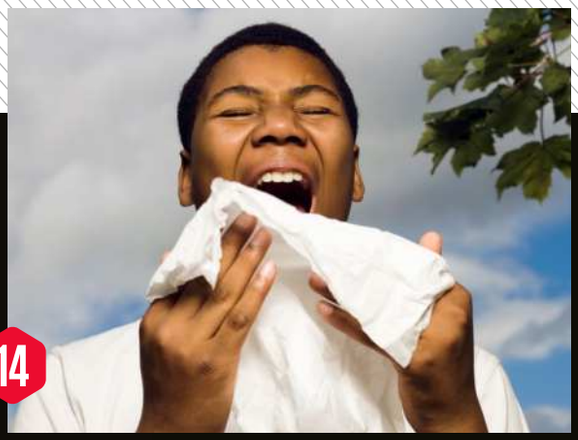
10 COOL DRINKS FASTER
If you need to make a drink cold in a short space of time, wrap a damp paper towel around it. The water in the paper towel will evaporate, cooling the bottle and its contents faster than the surrounding air would.

11 REDUCE COFFEE BITTERNESS
If you have a cup of coffee that tastes a bit too bitter for your liking, add a pinch of salt. When the salt dissolves, the sodium ions break off to block bitter molecules from your tongue.

12 TEARLESS ONIONS
When you cut into an onion, breaking its cells, sulphurous gases are released that can irritate the eyes and cause them to water. Keeping onions in the fridge can reduce the movement of the gas and prevent you crying as much.

13 THE POWER OF LEMONS
If you have cut a fruit, such as an apple or avocado, and want it to stay fresh for the next day, dip the cut surface in lemon juice. Fruit turns brown when exposed to oxygen, causing the enzyme polyphenol oxidase to react. The high acidity of lemon juice prevents this enzyme from working.





BODY CONTROL

Learn how to utilise your body better with these human biology hacks

STIFLE A SNEEZE

14 Sneezes happen when nerves in the nose send an impulse to the lower brain to contract the muscles in the throat and chest. A sneeze consists of two stages, called the sensation and respiratory stages. The sensation stage only lasts for a couple of seconds, but this is the crucial time in which you need to act if you want to stifle a sneeze before the reflux kicks in. To stop a sneeze, you need to overpower the impulse with a more intense one. Some methods include rubbing the roof of your mouth with your tongue, pressing the pressure point in between your eyebrows, tapping the top of your nose and pinching your top lip.

HEARING SPEECH

15 When you find yourself in a loud environment, struggling to hear what someone is saying to you, you might be tempted to turn your ear to hear better. But, which ear would you turn? In this case, you should turn your right ear. Scientists have discovered that the right ear is better at processing speech and logic, while the left ear picks up music better.

Did you know?

The human body has over 200 pressure points

MINIMISING MIGRAINES

16 For those suffering from migraines, pain can intrude unexpectedly. Knowing the most effective pressure points can help people feel more comfortable. Pressure points are specific sensitive areas of the body proven to relieve pain when a certain amount of pressure is applied to them. For children, research shows that ear pressure points such as the ear gate are most effective in reducing migraine pain. The ear gate is found at the top part of the ear, where it connects to the temple. Another pressure point to try when suffering from a headache is on the hand, between the base of the thumb and base of the index finger.

SEE IN THE DARK

17 If you've ever needed to go to the bathroom in the middle of the night and struggled to readjust to the dark bedroom, this is for you. When you need to switch quickly from a light to dark room, keep one eye closed the entire time. When you re-enter the dark room, simply switch which eye is closed. The one that wasn't exposed to the light will be better adjusted to see in the dark.

BED ASSOCIATION

18 Scientists have discovered that reading, working or using your phone in bed can interfere with your quality of sleep. In order to get the best night's sleep, you should use your bed primarily for sleeping. This will help your brain to associate being in bed with rest.

Baking soda and vinegar are often used to clean other parts of the kitchen, too

19 DRAIN UNBLOCKING

When drains become clogged, people often resort to using corrosive drain cleaning products. If you want to try a method with less harsh chemicals, try out this hack. Sprinkle a handful of baking soda down the drain, followed by twice as much vinegar. Baking soda and vinegar are at opposite ends of the pH scale, which measures how acidic or alkaline a substance is. When the two substances are combined in the drain, they begin to react with each other, releasing bubbles of carbon dioxide. As this reaction takes place in the drain, it can dislodge food and break up clogs.

20 THE DRINK THAT CLEANS

If the object is bigger than the container, cover a sponge in cola to soak it

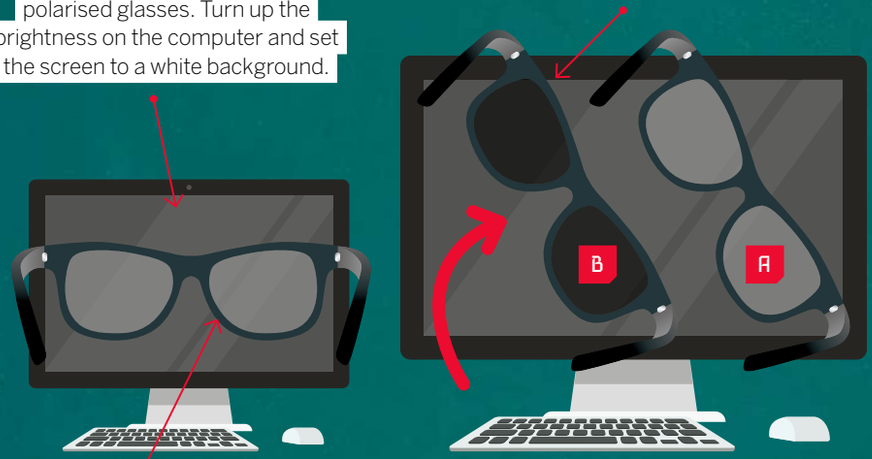
Thanks to the chemistry of cola, this soft drink can be used to remove rust from various objects. The phosphoric acid in the drink reacts with iron oxide in metal to dissolve rust and tarnish. To return a metal object to its original, shiny state, submerge it in cola for 24 hours. After this time, any remaining tarnish can be rubbed off easily with a scrubbing pad. Finally, rinse the metal to remove any sugary remnants and throw away the liquid to make sure nobody mistakes this rust-tainted cola for a refreshing drink.

21 TEST YOUR SUNGLASSES

Do your glasses have an anti-glare filter? Find out in a matter of seconds

COMPUTER SCREEN
Most computer screens have the same anti-glare technology as polarised glasses. Turn up the brightness on the computer and set the screen to a white background.

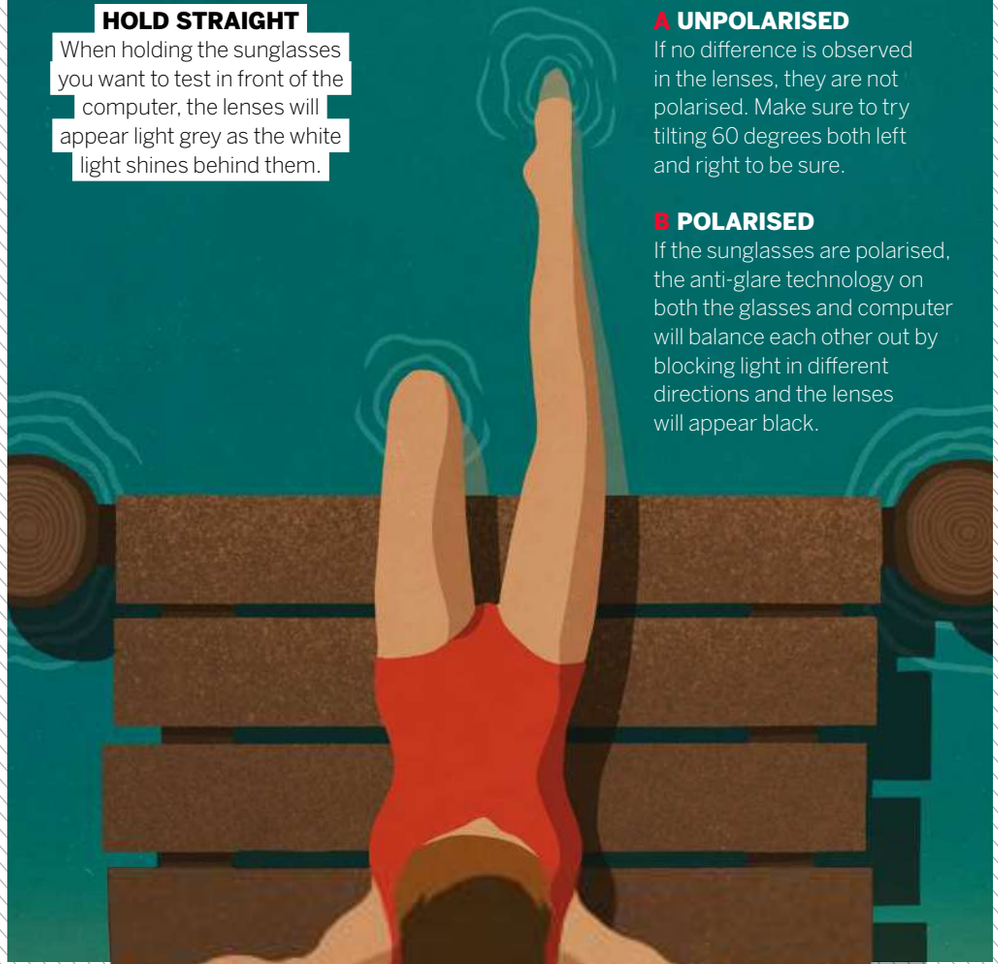
60 DEGREES
Tilt your sunglasses to a 60-degree angle. As the sunglasses are polarised horizontally – to only allow light through vertically – when they are held at an angle, different light waves are blocked.



HOLD STRAIGHT
When holding the sunglasses you want to test in front of the computer, the lenses will appear light grey as the white light shines behind them.

A UNPOLARISED
If no difference is observed in the lenses, they are not polarised. Make sure to try tilting 60 degrees both left and right to be sure.

B POLARISED
If the sunglasses are polarised, the anti-glare technology on both the glasses and computer will balance each other out by blocking light in different directions and the lenses will appear black.



Testing barrels for radioactive material

Uranium ore is a source of ionising radiation

HOW A GEIGER COUNTER WORKS

These handy devices measure radiation levels, producing an iconic clicking sound

WORDS **SCOTT DUTFIELD**

A Geiger counter, also known as the Geiger–Müller tube or G-M tube, is an inexpensive and useful instrument used to quickly detect and measure radiation. There are two types of radiation: non-ionising and ionising. Forms of non-ionising radiation, such as microwaves, have enough energy to shake atoms around, but not enough to knock electrons off them and change their composition. Ionising radiation, on the other hand, can strip atoms of their electrons in a process called ionisation. As a result, an ion pair is formed – a positively charged atom and a negatively charged electron. A Geiger counter exploits the natural process of ionisation to detect and measure radiation.

A Geiger counter houses a stable gas within its chamber. When exposed to radioactive particles, this gas ionises and creates an ion pair. This generates an electrical current that the counter typically records over a period of 60 seconds. When ionisation occurs and this current is produced, the device's speaker clicks and crackles every time an ion pair is formed, and a reading is given, often in millisieverts (mSv). There are several different types of radioactive particles that cause ionisation, known as either alpha, beta or gamma radiation. However, Geiger counters can not differentiate between the different types of radiation.

Exposure to ionising radiation can be damaging to human health. When this kind of radiation comes into contact with the atoms that make up our living cells, and in particular molecules of DNA, its energetic nature can disrupt, damage or alter them. Short exposures to some forms of radiation, such as X-rays for medical examinations, don't cause immediate health risks. However, prolonged exposure can lead to mutations in DNA and produce cancers. Geiger counters are an invaluable tool when evaluating a potential source of radioactivity.

Did you know?

The most radioactive element is radium

A Geiger–Müller counter used in detecting radioactivity and radiation

TYPES OF IONISING RADIATION

ALPHA RADIATION
These are charged particles that contain two protons and two neutrons, similar to he nucleus of a helium atom. They are heavy and slow moving, and can be blocked by a piece of paper or a thin layer of skin, making them significantly less hazardous than other types of radiation.

BETA RADIATION
These particles are similar to electrons, sometimes the counterparts of positrons. They are relatively light particles, around one-thousandth the mass of a proton. Natural sources of beta radiation are radioactively decaying elements such as uranium or actinium.

GAMMA RADIATION
Gamma radiation, also referred to as a gamma ray, is a form of electromagnetic radiation similar to X-rays. This radiation emits the highest energy photons – particles of electromagnetic radiation – in the electromagnetic spectrum. Gamma rays are highly penetrating and can easily pass through the body to cause damage.

DID YOU KNOW? More than 250,000 million tonnes of radioactive waste currently sits in storage globally

COUNTING IONISATION

How the Geiger-Müller tube uses simple science to detect dangerous radiation

1 WINDOW
Radiation particles enter the counter via a window which is thin enough for them to pass through. This is typically made of a mineral called mica.

2 RADIATION
Ionising radiation enters the tube and interacts with the gas within; this causes the electrons to break away from the gas atoms.

4 COUNTER
The counter, or reader, measures the amount of times a current is produced during ionisation to indicate the amount of radiation present.

GAS
An inert gas, such as helium or argon, fills the centre of the tube. This gas does not conduct electricity between the rod and the wall of the tube.

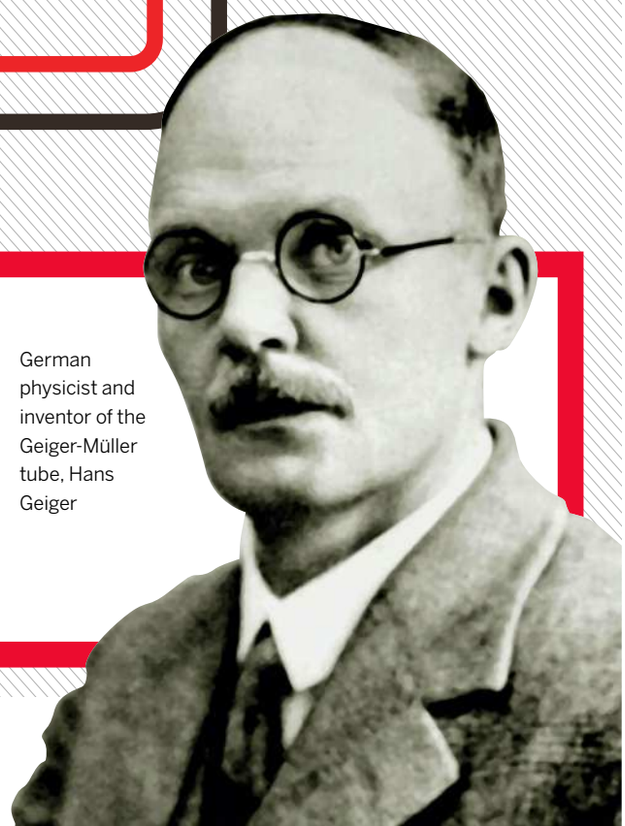
3 CURRENT
Once enough ionisation has occurred an electrical current is created between the positive rod and the walls of the tube.

ROD
The positively charged rod in the tube attracts free-flying electrons known as ions.

CREATING THE COUNTER

The Geiger counter was first conceptualised and designed by German physicist Hans Wilhelm Geiger and British physicist Ernest Rutherford in 1908, though their initial counter could only detect alpha particles. The pair used their counter to study alpha particles, and soon published the findings of several groundbreaking experiments such as the gold foil experiment, which ultimately revealed the nuclei of atoms to the world.

Between 1925 and 1928, Geiger and his PhD student Walther Müller improved the sensitivity of the counter to detect all types of ionising radiation. The design of the Geiger-Müller tube remains relatively unchanged in Geiger counters used today.



German physicist and inventor of the Geiger-Müller tube, Hans Geiger

TRANSPORT

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The vehicles and technology behind the Dakar Rally, the world's toughest cross-country race

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Inside the world's first clean-energy double-decker bus: the Hydroliner

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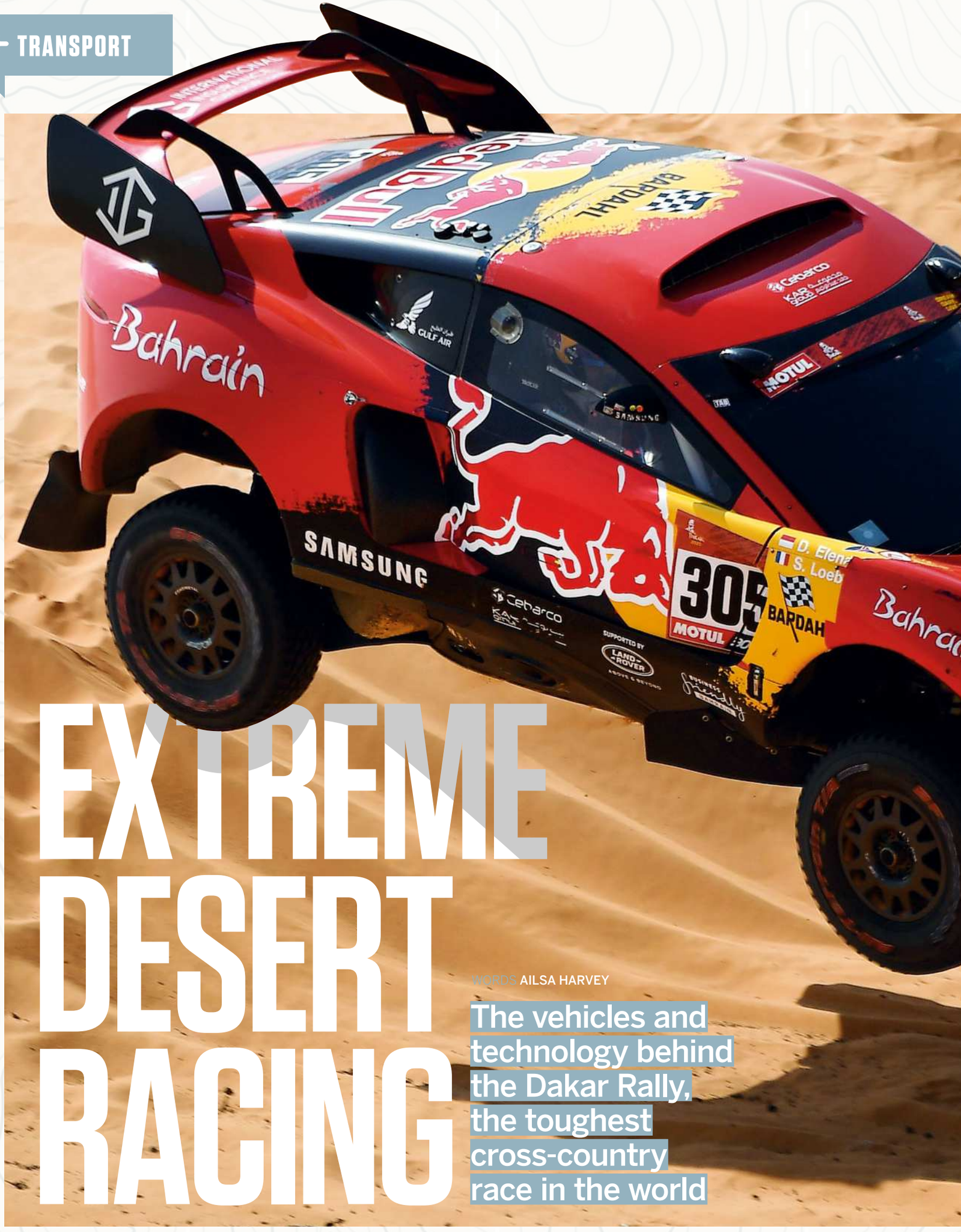


EXTREME DESERT RACING

WORDS AILSA HARVEY

The vehicles and technology behind the Dakar Rally, the toughest cross-country race in the world

The Bahrain Raid Xtreme, which debuted in the 2021 Dakar Rally

The Dakar Rally is designed for the extreme racer. Facing unpredictable terrain, severe temperatures and fearless speeds, competitors navigate some of the world's most desolate and challenging deserts in what's known as a 'rally raid'. In a range of vehicles, from lightweight motorbikes to sand-pounding mega-trucks, competitors battle it out in a test of physical endurance and unremitting concentration. Competitors need to drive across sand, rock and gravel for thousands of miles as they focus on navigating their sparse surroundings.

With no chance for a test run, the Dakar Rally requires racers to make their way through each segment using a set of specific instructions that are handed out on the day. Amateur drivers are given a physical copy on a sheet of paper, which they can attach to their vehicles, while the elite competitors can request an electronic copy. In 2022 the rally will take place entirely in the Arabian Desert of Saudi Arabia, the 30th country to host the race since its debut in 1978. There will be one stage per day over the course of nearly two weeks, including a marathon. In this stage, no assistance from support crews is allowed.

Did you know?
Racers often colour-code their roadbooks before the rally

The Dakar Rally is classed as the toughest motor race in the world. As well as perfecting their navigational abilities and performing fearless manoeuvres to contend for the podium, rally racers require a keen sense of adventure. After all, the event only began because of the risks one French motorbike rider took when competing in the Abidjan-Nice Rally in 1977: Thierry Sabine became lost in the Libyan Desert and was forced to navigate the sands back to familiar land. He loved the challenge and thrill that this provided so much that one year later he launched the now world-famous Dakar Rally.

DAKAR 2022 ROUTE

A broad overview of the course, the exact route is secret until the day of the rally

WHAT MAKES A WINNING RALLY CAR?

The Volkswagen Race Touareg achieved three consecutive wins at the Dakar Rally

CARBON-FIBRE MATERIAL
The car's outer body is made from light carbon fibre. In total the bodywork weighs 50 kilograms.

AIR INLET
Air is drawn into the vehicle here to cool the car's internal components.

COCKPIT CONDITIONS
In a relentless rally, it's essential that the driver is comfortable and can change the car's conditions. This includes manually adjustable air conditioning.

ENGINE POWER
The Touareg has a five-cylinder engine with a 2.5-litre capacity.

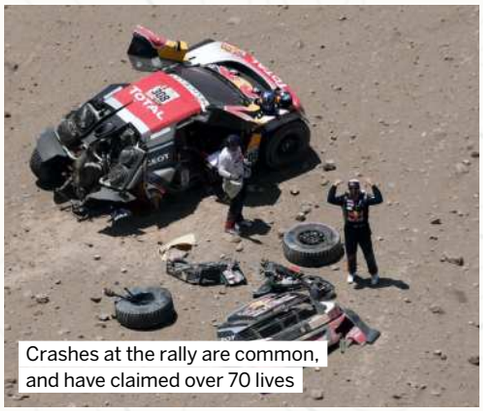
TUBULAR FRAME
The sturdy frame is made from aircraft steel. The tubular structures provide equal strength from any angle.

INTERCOOLING SYSTEM
The intercooler works to lower the temperature of the car's gas, reducing fuel consumption and increasing efficiency.

SUSPENSION
Dakar regulations mean that each wheel is limited to 250mm in spring travel.

> "Rally racers require a keen sense of adventure"

DID YOU KNOW? Some of the lorries that compete in the Dakar Rally are also support trucks for other vehicles



Crashes at the rally are common, and have claimed over 70 lives

An awards ceremony takes place at the end of the two-week event

PUNCTURE PREPARATION
The boot of the car is adapted to hold spare tyres. These are replaced in the event of a puncture.

OFF-ROAD WHEELS
The 25-centimetre-wide wheels ensure that a large area of tyre is in contact with the sand, spreading the weight across its surface.

Did you know?
The rally was held in Africa for 30 years and South America for 11

AR zone SCAN HERE

5 DAKAR CATEGORIES

1 MOTORBIKES
Bikers must have completed a leg of a World Cup or Dakar Series race to compete in the Dakar Rally. Elite riders are given yellow number plates to set them apart.

2 QUADS
Quad bikes can be two-wheel drive or four-wheel drive. The maximum engine capacities are 750cc and 900cc respectively.

3 CARS
Rally cars are usually designed with a fibreglass or carbon frame. Many are similar to 4x4s that you would find in a dealership, but they are modified to include features such as a roll cage. This sturdy frame protects the driver in the case of the car rolling over.

4 TRUCKS
The most common trucks are prototypes, but components such as the cabin must be production-based. Their speeds can reach up to 87 miles per hour.

5 LIGHTWEIGHT VEHICLES
These vehicles have fuel tanks of 130 litres or less, giving them a range of 155 miles. Their shorter range means they use the same refuelling stations as motorbikes.

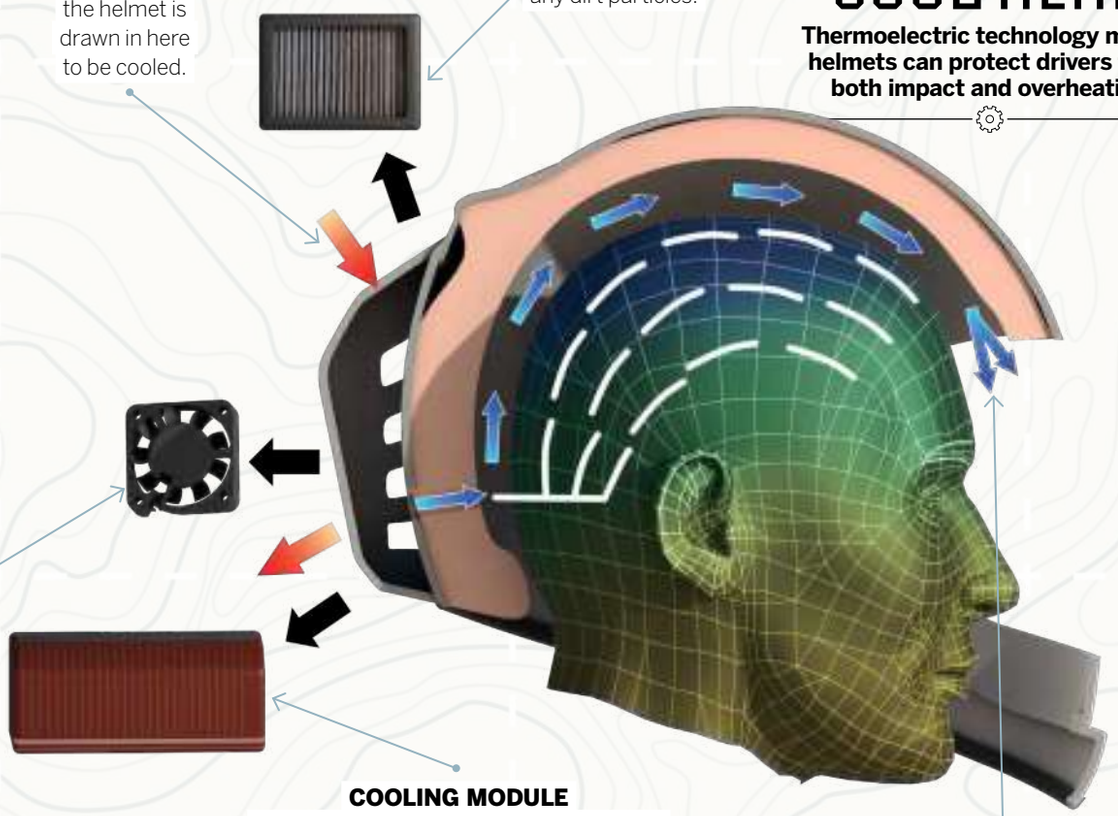
COOLING WITH SPACE TECHNOLOGY

Controlling the temperature of vehicles and drivers is essential in any off-road endurance event. However, during the Dakar Rally, which famously traverses sweltering desert lands, cooling technology has an increased priority.

In the past, technology used by the European Space Agency (ESA) has been incorporated into the Dakar Rally. One piece of technology used in vehicles is a thermal screen, which was also used in one of the ESA's space launch vehicles. The screen wraps around the exhaust pipe and can cool it by 700 degrees Celsius. In addition to the car's temperature, rally drivers have been known to use self-cooling drink containers and air-conditioned helmets.

KEEPING A COOL HEAD

Thermoelectric technology means helmets can protect drivers from both impact and overheating



AIR IN
The air surrounding the helmet is drawn in here to be cooled.

FILTER
As the air will be inhaled, it's first filtered to remove any dirt particles.

FAN
To keep the air flowing, a fan blows it through the helmet.

COOLING MODULE
This thermoelectric module transfers heat between its two halves. When an electric current runs through this device, all the heat moves to one side, making one half hot and the other cold.

AIR DISTRIBUTION
After the air is cooled by the module, it travels through large gaps in the fabric, reducing the temperature at the surface of the competitor's head.

The Dakar Rally has taken place in temperatures up to 40 degrees Celsius. This can create temperatures 20 degrees hotter inside the cars

Temperatures can exceed 50 degrees Celsius in the deserts of the Arabian Peninsula

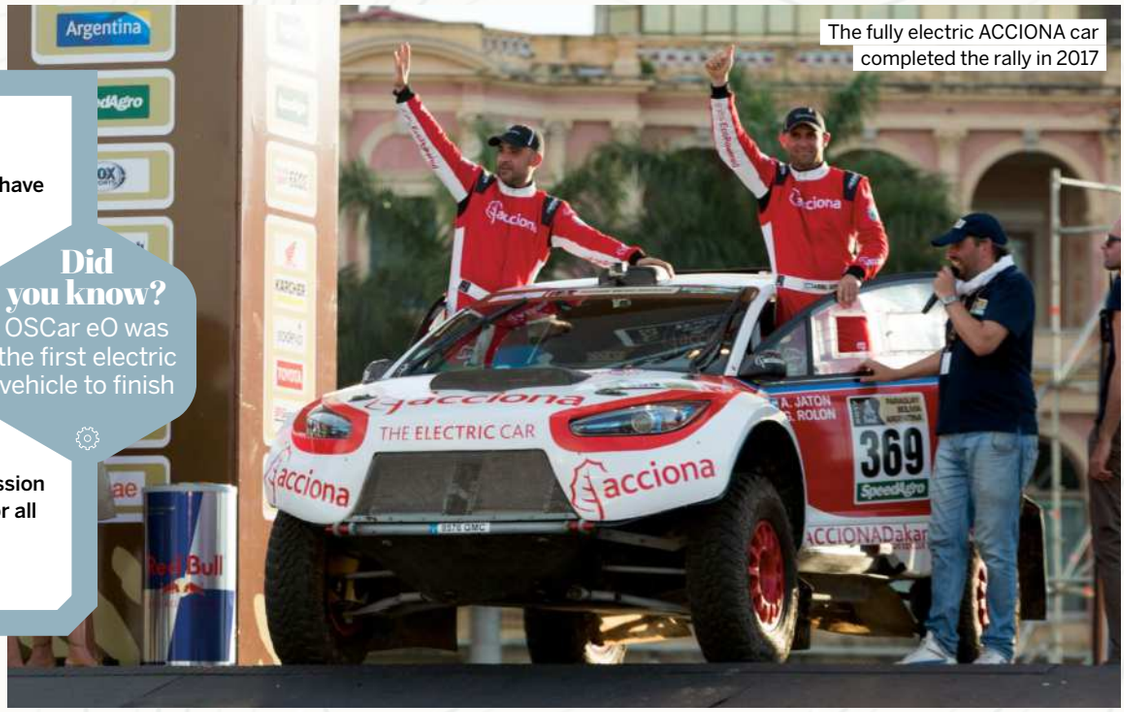
AR zone SCAN HERE

DID YOU KNOW? Mitsubishi is the manufacturer with the most Dakar Rally wins in the car category

GREEN BY 2030

The organisers of the Dakar Rally have launched 'DakarFuture', a plan to transition towards a lower emission event. In 2022 a new category – the 'alternative energy' category– could be added to the rally. This would include hydrogen-powered, electric and hybrid vehicles. In 2026 the car and truck categories will need to meet new requirements regarding their emission levels. The aim of this project is for all cars and trucks to run on green energy by the 2030 event.

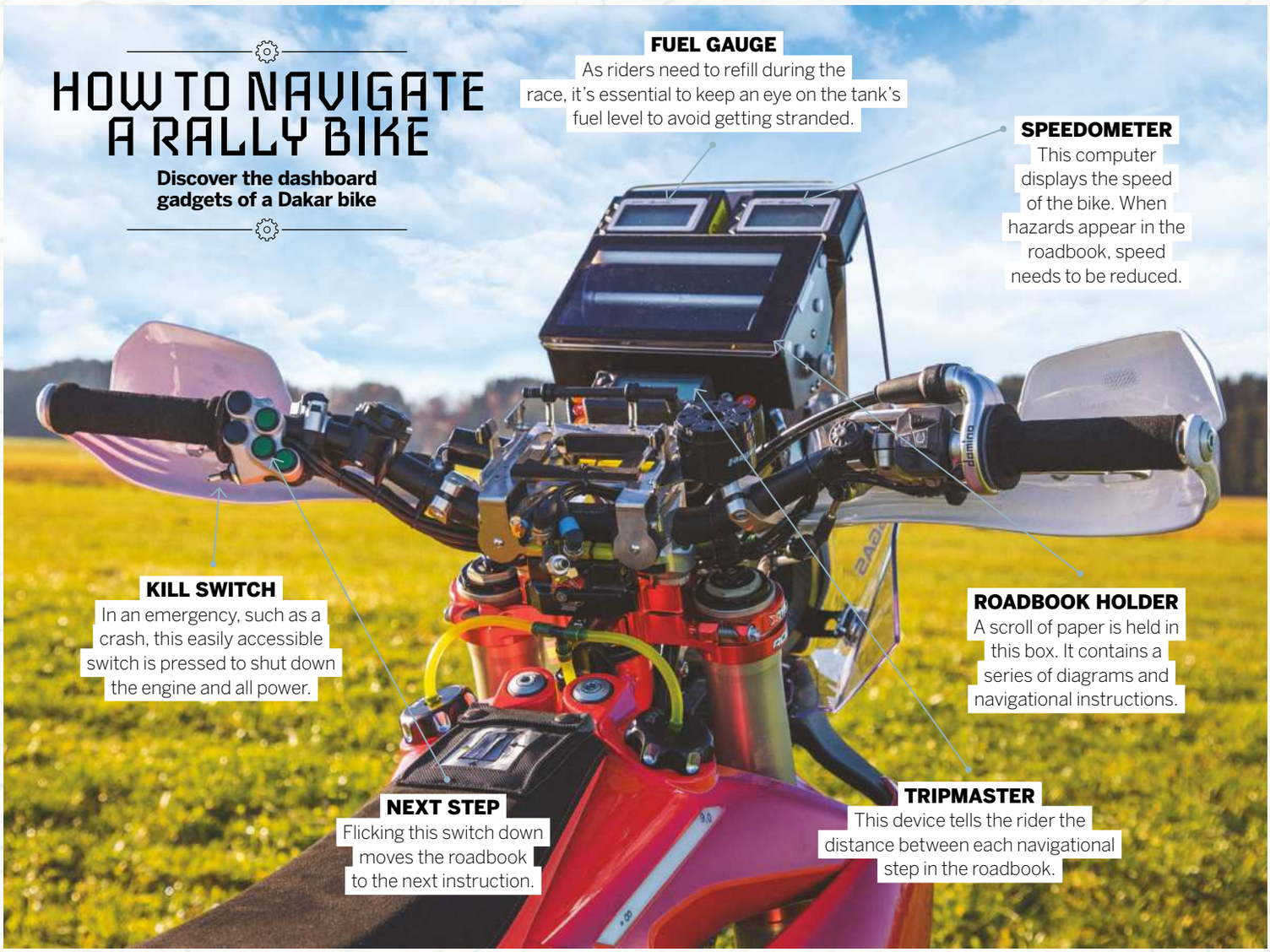
Did you know?
OSCar eO was the first electric vehicle to finish



The fully electric ACCIONA car completed the rally in 2017

HOW TO NAVIGATE A RALLY BIKE

Discover the dashboard gadgets of a Dakar bike



FUEL GAUGE
As riders need to refill during the race, it's essential to keep an eye on the tank's fuel level to avoid getting stranded.

SPEEDOMETER
This computer displays the speed of the bike. When hazards appear in the roadbook, speed needs to be reduced.

KILL SWITCH
In an emergency, such as a crash, this easily accessible switch is pressed to shut down the engine and all power.

ROADBOOK HOLDER
A scroll of paper is held in this box. It contains a series of diagrams and navigational instructions.

NEXT STEP
Flicking this switch down moves the roadbook to the next instruction.

TRIPMASTER
This device tells the rider the distance between each navigational step in the roadbook.

HYDROGEN BUS POWER

Inside the world's first clean-energy double-decker bus: the Hydroliner

WORDS AILSA HARVEY

Due to global demand, we are running out of the fossil fuels that are used to power vehicles on the roads. Hydrogen, on the other hand, is accessible everywhere across the globe and has a high energy content per unit of weight. There is plenty of hydrogen on Earth to be used as vehicle fuel, being the third most abundant element on its surface after oxygen and silicon – but it doesn't exist naturally in its pure form. In order to produce the fuel, hydrogen needs to be extracted from compounds such as water and methane.

The first hydrogen-powered car was invented in 1806, but after two centuries this technology now exists in much larger machines. Hydrogen as a fuel presents a more sustainable, zero-emission alternative to fossil fuels. Its potential is being shown in public transport, too, in the form of the first hydrogen double-decker bus: the Hydroliner.

Manufactured by Wrightbus, the Hydroliner releases pure water from its exhaust. The electrical energy created inside this type of vehicle is produced in a fuel cell that replaces diesel engines. The fuel cell mixes pure hydrogen with an influx of oxygen. The end product is electricity, with heat and water as by-products. In cities where the surrounding air is heavily polluted, hydrogen vehicles can be used to reduce greenhouse gas emissions for clearer air and to help slow global warming.

Did you know?
The first double-deckers emerged in 1847

DID YOU KNOW? Hydrogen makes up a small percentage of Earth's atmosphere, but is abundant in water and organic matter

WHERE ARE THE FUEL STATIONS?

With a big appetite for hydrogen fuel, the Hydroliner bus needs to be driven within range of a hydrogen fuel station. These services currently vary based on demand in the area. The fuel can be produced at the station, with the gas made locally and then transported to the site.

When topping up the hydrogen tanks, the process for the driver is similar to filling up a petrol or diesel tank, though the high pressure that hydrogen leaves the pump at often makes loud noises. When the pump makes contact with the bus, it clicks into place to ensure contact before releasing any fuel.

The Hydroliner buses that have been distributed in Aberdeen, Scotland, are powered by hydrogen that is produced locally. Electrical energy is created on wind and water farms and used to remove the hydrogen from water.

At the end of 2020, there were 553 hydrogen fuelling stations in the world

HYDROLINER COMPONENTS

How is Wrightbus' hydrogen-powered vehicle engineered?

The world's first double-decker hydrogen fuel cell-powered electric vehicle

GAS STORAGE
1,120 litres of hydrogen is stored in impact-resistant cylinders at high pressure.

FUEL CELL
The hydrogen is carried at a lower pressure to the fuel cell, where it is split into protons and electrons to form an electric current.

ELECTRIC PORTAL AXLE
Centrally placed, this device delivers electricity to the bus' wheels to turn them.

BATTERIES
Electricity made in the fuel cells is transported to the 48 KWh lithium battery pack to power the vehicle.

COOLING SYSTEM
By cooling the hydrogen, it becomes more dense. This means that more energy can be created from it per unit of volume.

REFUELLING POINT
Hydrogen is pumped into the bus at this point, a process that takes eight minutes to refill completely for a range over 250 miles.

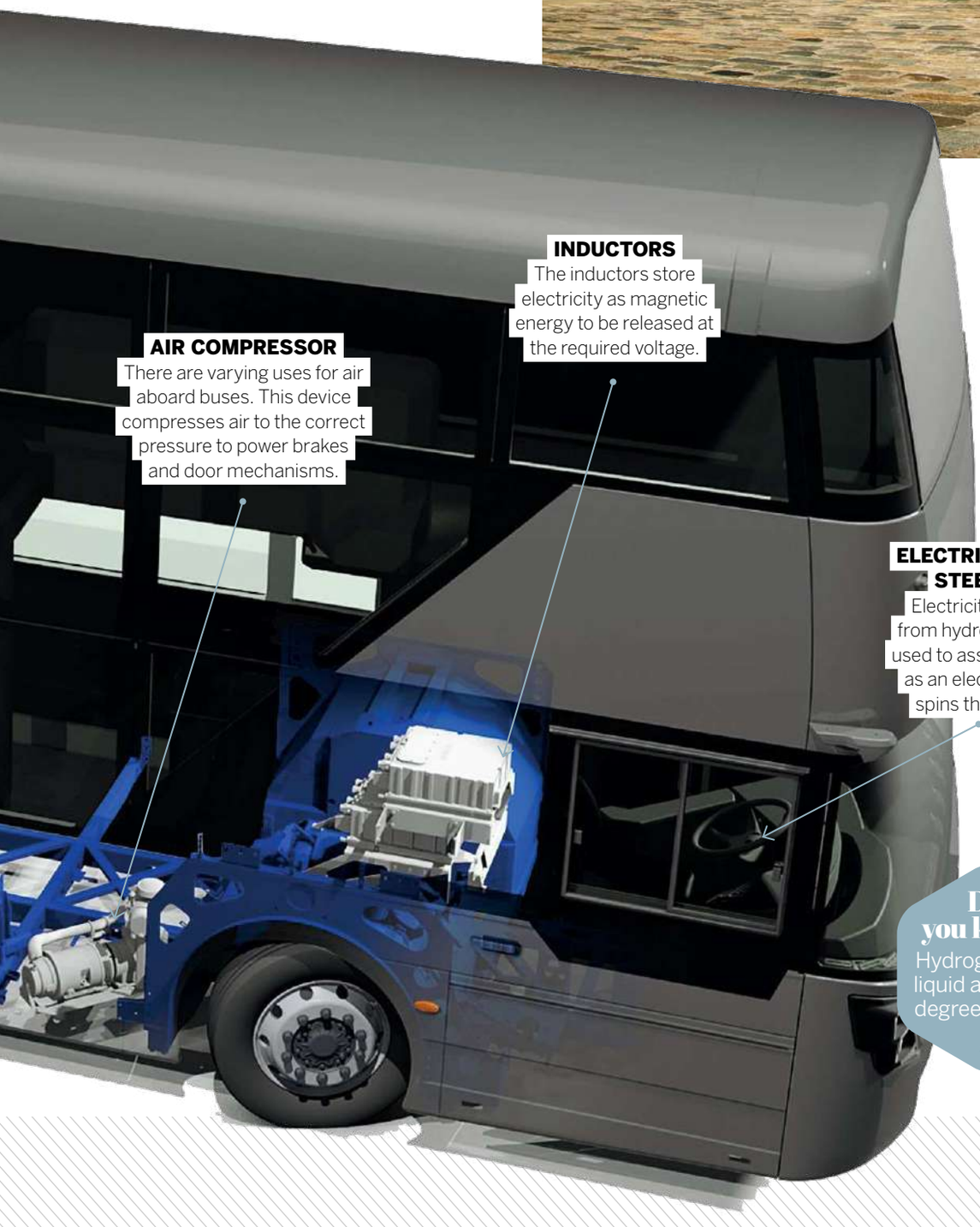
"The fuel cell mixes pure hydrogen with an influx of oxygen"

DID YOU KNOW? Seven months after launch, the Hydroliner had prevented 500,000 kilograms of carbon dioxide entering the atmosphere

PASSENGER EXPERIENCE

The Hydroliner can hold up to 86 passengers. These buses currently run in the cities of Birmingham, London, Belfast, Dublin and Aberdeen in the UK and Ireland, working to reduce pollution for residents and visitors. Because the chunkiest items, the hydrogen cylinders, slot into the back of the bus, and without a central engine taking up significant space, the passenger area is not compromised. And instead of a running engine creating background noise, there is minimal sound. It bodes well for quieter cities and is less disturbing to peaceful countryside routes.

There are 20 Hydroliner buses in use in Birmingham



INDUCTORS
The inductors store electricity as magnetic energy to be released at the required voltage.

AIR COMPRESSOR
There are varying uses for air aboard buses. This device compresses air to the correct pressure to power brakes and door mechanisms.

ELECTRIC POWER STEERING
Electricity created from hydrogen is also used to assist steering, as an electric motor spins the wheels.

Did you know?
Hydrogen turns liquid at -252.87 degrees Celsius

5 FACTS METHODS FOR PRODUCING HYDROGEN

1 GASIFICATION
Hydrogen, carbon monoxide and carbon dioxide are formed when natural gas reacts with high-pressure steam.

2 ELECTROLYSIS
Water can be manipulated and split into hydrogen and oxygen when an electric current passes through it.

3 RENEWABLE LIQUID REFORMING
At high temperatures, steam can be used to remove hydrogen from liquid fuels such as ethanol.

4 FERMENTATION
Bacteria can be used to break down organic matter, releasing hydrogen as it does .

5 WATER SPLITTING
Photoelectrochemical water splitting involves turning solar energy into electricity to remove hydrogen from water.

Changing gears on mountain bikes allows riders to travel across varied terrain

HOW PUSH BIKE GEARS WORK

Understanding this mechanism can improve your control over your bicycle

WORDS **AILSA HARVEY**

When riding a bike, a high gear is optimal for sustaining high speeds and descending, while a low gear provides a comfortable pedalling speed for climbing hills. However, no single gear is optimal for tackling all terrain – this is why bikes have a gear system.

As the pedals on a bike turn, they rotate a chainring, causing the bike's chain to circulate between the pedals and the rear wheel. At the centre of the rear wheel, the chain attaches to one of a series of cogs. When the gear is changed, the chain jumps between them. The mechanism responsible for causing these movements is called a derailleur.

When set at a low gear, the chain attaches to the largest cog on the cassette, closest to the bike's frame. In this gear, one full rotation of the pedals equals fewer turns of the rear wheel than when in harder, or higher, gears. Pedalling requires less force in low gears and feels more comfortable when cycling uphill. As you move up through the gears, the wheel rotates more with a single rotation of the pedals. Each rotation per pedal gives the gear ratio.

Most modern road bikes will have a derailleur at both the front and back of the bike, multiplying the number of gears available to the rider. A bike with only one chainring at the front and a cassette at the back with 11 cogs gives the cyclist a total of 11 gears. However, bikes with two front chainrings, with two cogs, provide 22 gears. When riding a bike with two chainrings or more, the chain is moved across to the larger chainring to reach higher gears, and so the highest gear is when the chain is on the largest chainring at the front, but the smallest cog at the back.

Did you know?

Mechanical and electronic shifting can be used to change gears

HANDLEBAR SHIFTERS

To control the gears at the front of the bike, a cyclist uses their left handlebar, while the right controls the gears on the cassette at the back. Not all bikes have two chainrings, but all have gears at the back. The handlebar controls are called shifters, as they are used to shift the chain onto different cogs.

When changing gears, it's important to pedal at the same time, as this allows for a smooth transition across cogs. Many bikes display a number on the handlebars to show what gear the bike is in. How gears are changed depends on the bike. Usually part of the handlebar needs to be twisted towards or away from the rider to move the gear number up or down. In other bikes, a small lever is pushed up and down with the thumb. Higher numbers indicate higher gears.

When using shifters on road bikes, the protruding levers are pushed inwards, towards the centre of the handlebars, to click down a gear. A smaller button is pushed inwards to move into a higher gear. The shifters are the same levers used to bring the bike to a stop. When pulled towards the cyclist, as opposed to inwards, the brakes are applied.

To change gears, a cyclist reaches for the lever in front of the handlebars

DID YOU KNOW? The first geared bike was invented by James Starley in 1871, called the Ariel

GEARS IN MOTION

How a derailleur works

CAGE
Connecting two pulleys, the length of a bike's cage determines how much slack the derailleur can take. Generally, the larger the biggest cog in the cassette, the longer the cage needs to be.

CASSETTE
This collection of cogs (also called sprockets) are all different sizes and are located at the centre of the rear wheel.

CHAINRING
The chain slots onto the chainring near the bike's pedals. When the pedals turn, so does the chain. Typically, bikes have between one and three of these.

GUIDE PULLEY
This guides the chain into the chainwheel as gears are changed.

CABLE AND PINCH BOLT
A bolt attaches the cage to a cable which connects the derailleur to the handlebars. When the gears are changed, the cable is pulled or released and the cage is moved inwards or outwards.

TENSION PULLEY
When this pulley pulls back, it increases tension in the chain. Without this, the chain would hang loose when in lower gears and slip off the chainwheel.

CONNECTING CHAIN
The bike's chain connects the chainring near the centre of the bike and the cassette towards the back.

GEAR HUBS

A gear hub is considered by some cyclists to be the future of bike gears, as it keeps the number of gear ratios high without the bike requiring two derailleurs. The gears are contained within the device's shell as opposed to the cogs on traditional bikes, which are exposed to the elements. To turn the rear wheel faster than the chain, small gears rotate inside a gear ring, which is connected to the bike's external cog. The central sun gear (yellow) is fixed and doesn't move. Rotating around this are planet gears (blue) with teeth that interlink with the large ring gear (red). As the cyclist pedals, the planetary gears move against the ring gear, spinning it faster than the pedals' rotation to turn the rear wheel. A series of these gear structures can be found inside a gear hub. Depending on the selected gear ratio, a different one connects to the external cog. Planet gears with less teeth push the wheel around further for each pedal.

A series of ring, planet and sun gears can be found in internal gear hubs

INSIDE THE SECRET SPACE PLANE

What do we know about the US Department of Defense's X-37B orbital vehicle?

WORDS **ADAM MANN**

DID YOU KNOW? The X-37B was awarded the Collier Trophy, a most prominent aviation award, for its contribution to space travel

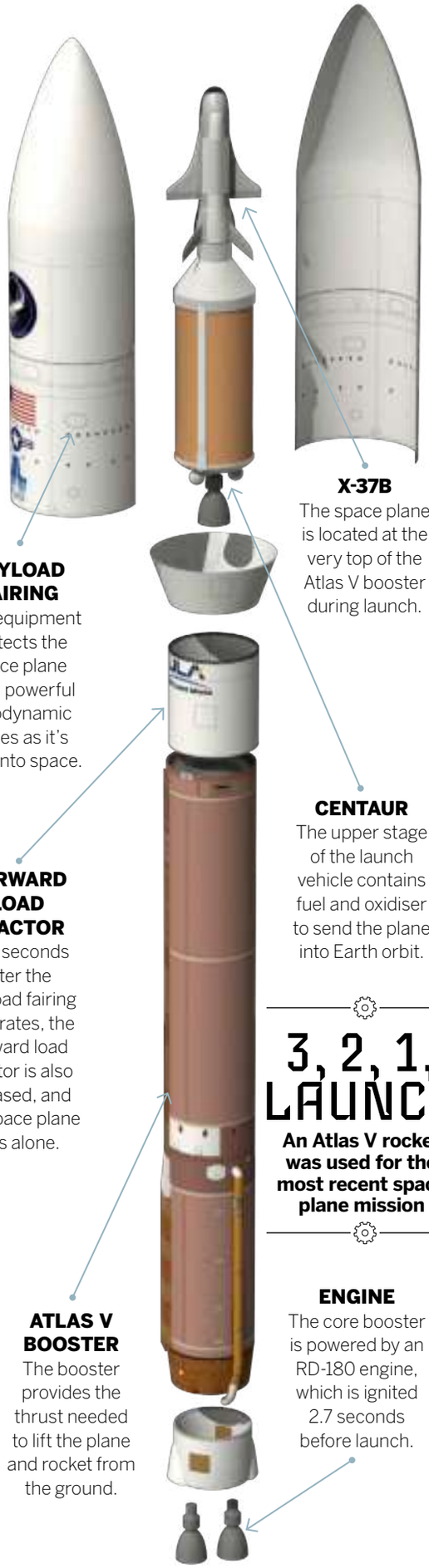
Did you know?
The plane can change orbit patterns by flying low

The design improves on the Space Shuttle

The uncrewed X-37B spy plane is one of the most intriguing spacecraft in the world, flying regular covert missions whose purposes aren't fully known. However, over the years more information about the craft, which is also known as the Orbital Test Vehicle (OTV), has come to light one tidbit at a time. The reusable craft, resembling a smaller version of one of NASA's now-retired Space Shuttles, was originally built by NASA in 1999. It's around 8.8 metres long and 2.9 metres tall, with a wingspan of slightly less than 4.6 metres. It weighs 4,990 kilograms when on the launchpad.

Like the Space Shuttles before it, the X-37B takes off vertically and is propelled by a rocket. Once in orbit, it can manoeuvre on its own, and it eventually lands on a runway back on Earth, much like a conventional plane. The vehicle has a small payload area – roughly the size of a pickup truck bed – enabling it to carry gear and satellites. It operates at altitudes between 110 and 500 miles above Earth. NASA transferred two X-37B vehicles to the Pentagon's Defense Advanced Research Projects Agency (DARPA) in 2004. After being operated by the US Air Force for many years, the robotic spy planes came under the purview of the newly established Space Force in 2020.

An X-37B stored in a hangar



PAYLOAD FAIRING
This equipment protects the space plane from powerful aerodynamic forces as it's fired into space.

X-37B
The space plane is located at the very top of the Atlas V booster during launch.

FORWARD LOAD REACTOR
Five seconds after the payload fairing separates, the forward load reactor is also released, and the space plane flies alone.

CENTAUR
The upper stage of the launch vehicle contains fuel and oxidiser to send the plane into Earth orbit.

3, 2, 1, LAUNCH
An Atlas V rocket was used for the most recent space plane mission

ATLAS V BOOSTER
The booster provides the thrust needed to lift the plane and rocket from the ground.

ENGINE
The core booster is powered by an RD-180 engine, which is ignited 2.7 seconds before launch.

X-37B MISSIONS

PLANE DEBUT
In April 2010, the space plane was launched into orbit, where it remained for 224 days. This mission was called OTV-1, short for Orbital Test Vehicle 1.

DOUBLE TIME
The OTV-2 mission was launched using a different X-37B. This mission lasted over twice as long as the first, totalling 468 days and beginning in March 2011.

RETURN TO THE ORIGINAL
OTV-3 saw the use of the same plane as OTV-1. It flew for 674 days between December 2012 and October 2014.

SMOOTH LANDING
OTV-4 began on 20 May 2015, using the same plane as OTV-2. It spent 718 days in space before performing the first X-37B landing at NASA's Shuttle Landing Facility in Florida.

FALCON 9 LIFTOFF
On 7 September 2017, OTV-5 was launched from NASA's Kennedy Space Centre, returning 780 days later. It carried experiment apparatus to test oscillating heat pipe technologies in space conditions.

2020 MISSION
The latest mission was launched on 17 May 2020 using the Atlas V. This was the first to carry an added experiment module to increase its productivity.

WHAT'S IT UP TO?

Despite flying six missions, its true purpose remains a mystery. Some possibilities include surveillance of Earth's surface and deploying spy satellites, though nothing has been confirmed. More out-there theories have been proposed, such as the notion the X-37B could be a space-based bomber, a vehicle for spying on the Chinese space station or a means for the US military to interfere with other countries' satellites. Experts have splashed cold water on all these ideas, saying they would require large amounts of fuel or would be too easy to trace back to the US military.

Technicians carry out checks on Orbital Test Vehicle 1

EXPERIMENT MODULE

Shortly before the most recent X-37B launch, the US military revealed the spy plane had a new service module that allowed for large numbers of experiments to be carried to orbit. The mission deployed a small satellite known as FalconSAT-8, containing five experimental payloads, some developed by the US Air Force and some by NASA. While NASA has stated that it was flying an experiment on a previous X-37B flight, this was the first time the military had disclosed any specifics about such cargo.

The new experiment module is seen attached to the outside of the plane.

The X-37B is enclosed in the protective payload fairing

Did you know?
The X-37B can be launched by different rockets

ADVANCED TECHNOLOGY

The instruments and materials that make the X-37B's mission goals achievable

AVIONIC EQUIPMENT
The space plane has an autonomous guidance system. Its avionics allow the vehicle to deorbit and land without a crew.

JET FUEL TANK
The fuel tank at the front of the plane is filled with kerosene. Kerosene is a compact fuel and can withstand extreme temperatures.

MANOEUVRING THRUSTERS
Electric thrusters are used to move the plane while in orbit.

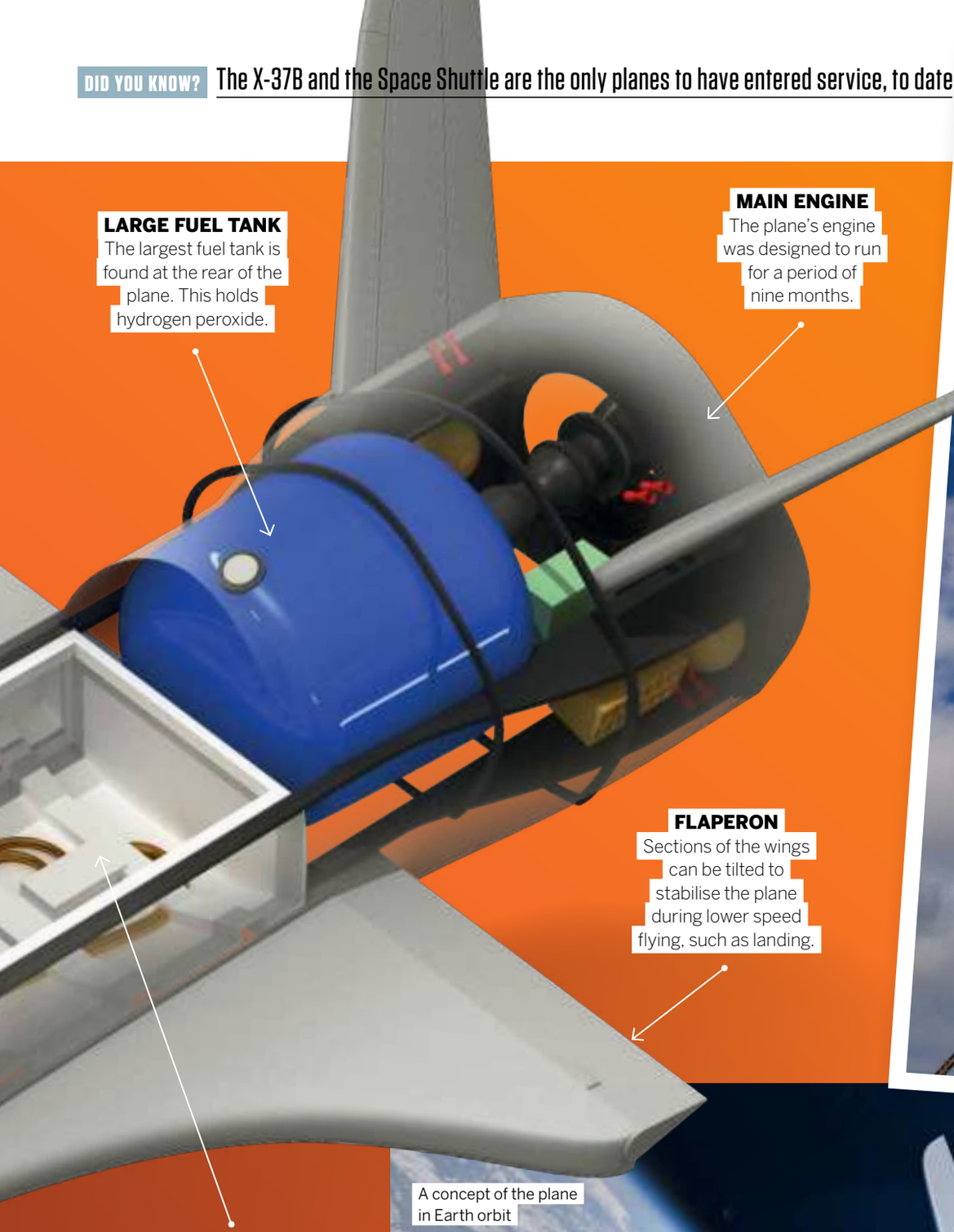
DID YOU KNOW? The X-37B and the Space Shuttle are the only planes to have entered service, to date

LARGE FUEL TANK
The largest fuel tank is found at the rear of the plane. This holds hydrogen peroxide.

MAIN ENGINE
The plane's engine was designed to run for a period of nine months.

FLAPERON
Sections of the wings can be tilted to stabilise the plane during lower speed flying, such as landing.

EXPERIMENT BAY
This empty bay can be filled with experiments and other equipment, adding versatility to each flight.

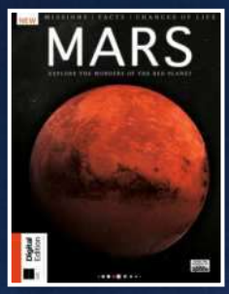


The Atlas V is a dependable rocket responsible for many successful spacecraft launches since its inaugural flight in 2002

A concept of the plane in Earth orbit

"The vehicle has a small payload area – roughly the size of a pickup truck bed – enabling it to carry gear and satellites"

Find out everything you've ever wanted to know about outer space



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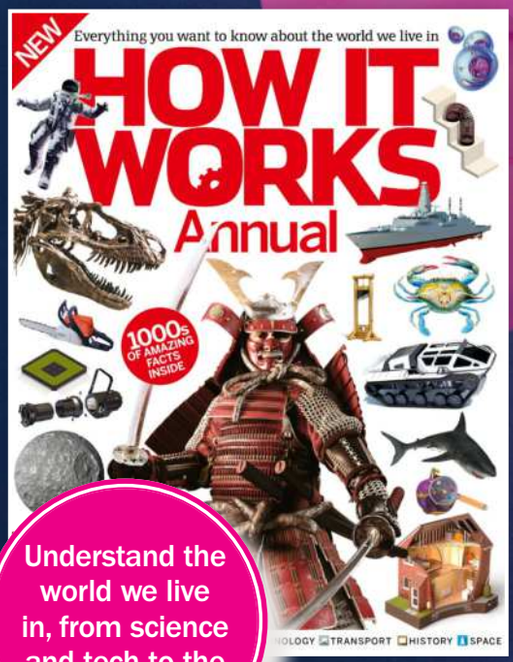

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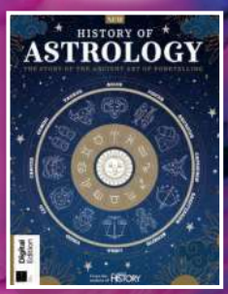

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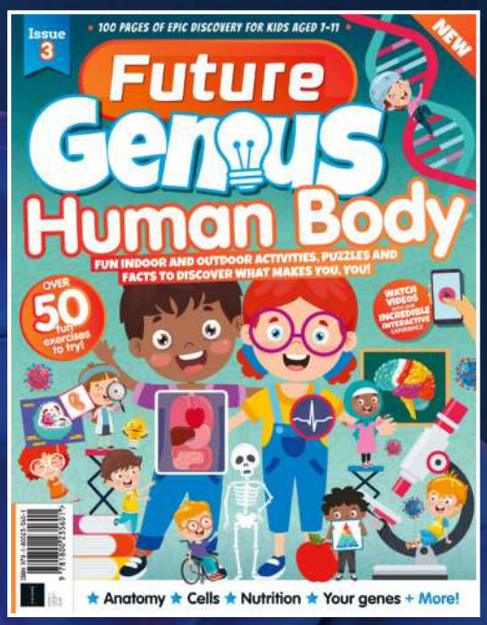

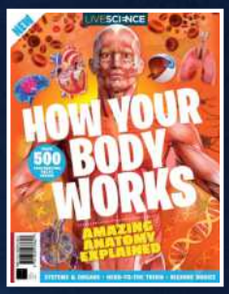

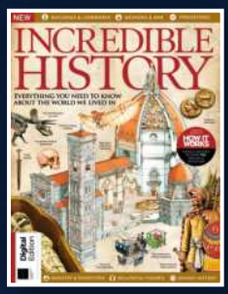

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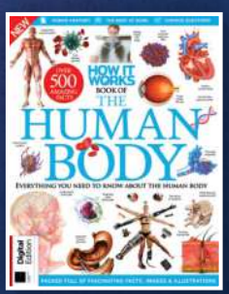

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